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Movement and Behavior of Walleye, Stizostedion Vitruem Vitreum (Mitchell), in Jamestown Reservoir, North Dakota, As Determined by Biotelemetry

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MOVEMENT AND BEHAVIOR OF WALLEYE, STIZOSTEDION VITREUM VITREUM (MITCHILL), IN JAMESTOWN RESERVOIR, NORTH DAKOTA, AS DETERMINED BY BIOTELEMETRY

by
Clinton B. Hall

Bachelor of Science, University of North Dakota, 1979

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for the degree of

Master of Science

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1982

This Thesis submitted by Clinton B. Hall in partial fulfillment of the requirements for the Degree of Master of Science from the University of North Dakota is hereby approved by the Faculty Advisory Committee under whom the work has been done.

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This Thesis meets the standards for appearance and conforms to the style and format requirements of the Graduate School of the University of North Dakota, and is hereby approved.

A. William Johnson
Dean of the Graduate School

Permission

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ABSTRACT

Radio biotelemetry was used to study the movements and behavior of walleyes in Jamestown Reservoir during the summer of 1980. Four walleyes weighing from 1.7 to 4.4 kg were surgically implanted with radio transmitters. Only one fish could be successfully tracked. It was found that conductivity prevented the reception of radio signals from water deeper than 4.5 m. In 1981, eight walleyes were surgically implanted with ultrasonic transmitters. The ultrasonic transmitters performed as expected. Seven walleyes were successfully tracked throughout the summer. Two of the walleyes appeared to be nomadic and did not form activity areas. Five walleyes formed activity areas, with two fish having multiple activity areas. The average size of the activity area was 45.4 ha. Three types movement patterns were observed; directional, random, and movements following the shoreline. Walleyes were seldom found resting. The walleyes moved into deeper water as the summer progressed. Four to five meters was the average locational depth. Light did not limit the fish's activity in shallow water. No relationship was evident between weather conditions and other outside influences on walleye activity.

INTRODUCTION

The walleye, Stizostedion vitreum vitreum (Mitchill), ranks second only to largemouth bass, Micropterus salmoides (Lacepede), as the preferred freshwater game fish throughout the United States. However, walleyes are the most preferred game fish in North Dakota (Cassity 1979). Many of North Dakota's natural lakes do not support large walleye populations. Reservoirs provide most of the walleye sport fishery within the state. A North Dakota State Game and Fish Department survey reported that over 75% of the walleyes harvested in the state were from reservoirs (Duerre 1977).

Precise management of the walleye is desirable for the conservation of this valuable resource. Currently, the literature contains little information on behavioral aspects of walleye life history in reservoirs. Biologists need to know the effects of physical and biological factors on the activity patterns and movements of this species. The knowledge gained may lead to the development of better management methods.

The objectives of this study were to: (1) assess the application of biotelemetric techniques for the study of walleyes in North Dakota reservoirs; (2) determine the extent of movements and home range; (3) evaluate habitat usage; and (4) describe the effects of environmental factors on walleye movement and activities.

DESCRIPTION OF STUDY AREA

Jamestown Reservoir is located in south eastern North Dakota ear the city of Jamestown (Fig. 1). The reservoir was formed by the mpoundment of the James River in 1954 (Hanson 1978). Jamestown eservoir is maintained for flood control, fish production, and rec- eation (U.S. Bureau of Reclamation 1974). It will also regulate lows coming from the Garrison Diversion Irrigation Project.

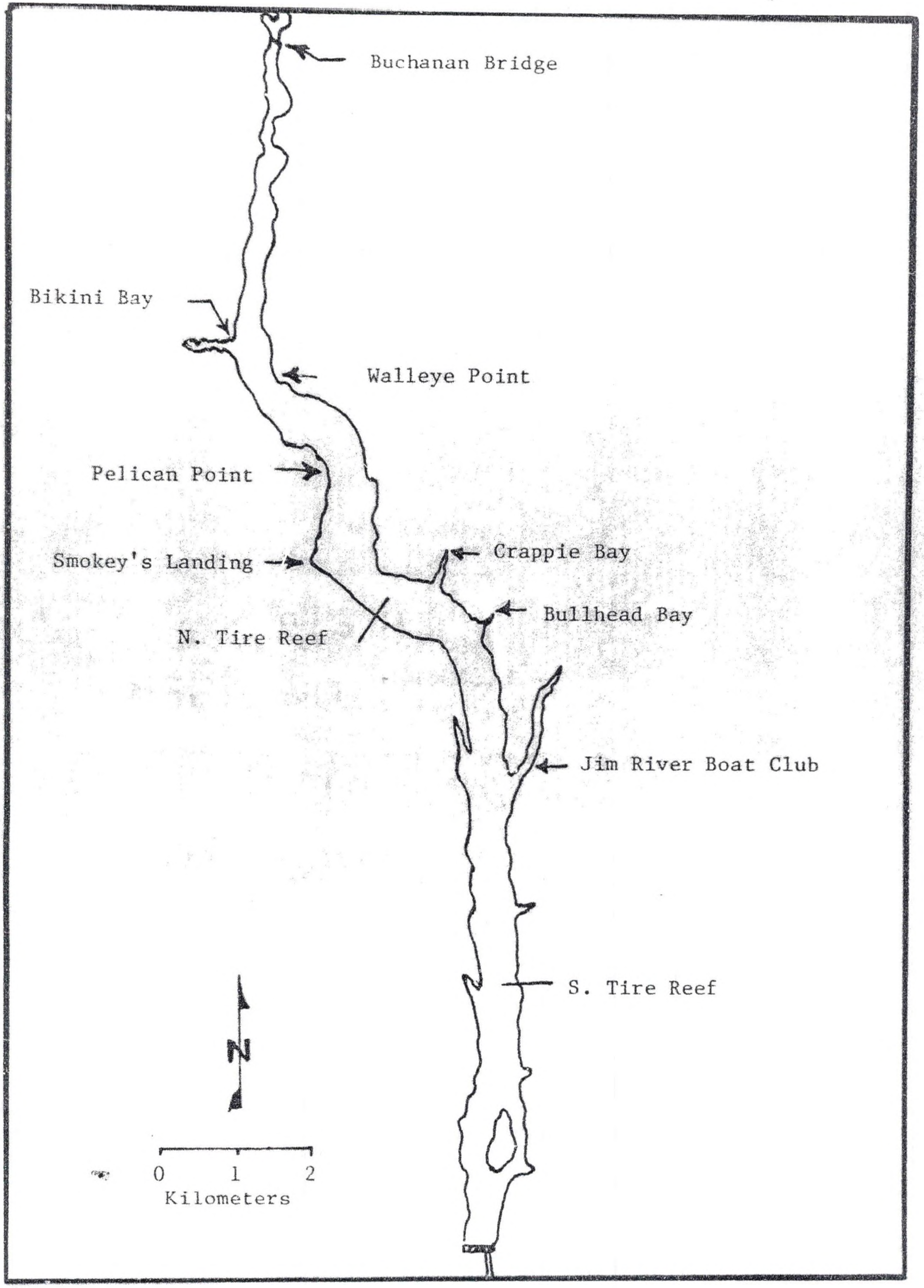
The drainage area above the dam is approximately 1940 km^2. James- own Reservoir has a surface area of 800 ha with a mean depth of 4.2 m t normal pool at 1430 feet above mean sea level (msl) (Hanson 1978). he maximum depth near the face of the dam is approximately 12 m. The eservoir is approximately 17 km long with an average width of 0.4 km.

The reservoir is eutrophic. The U.S. Environmental Protection gency (1976) in its National Eutrophication Survey ranked Jamestown eservoir seventh in overall trophic quality among 14 North Dakota lakes nd reservoirs. Extensive algal blooms occur during the summer. urbidity is quite high. Secchi disk readings are usually 1 m or less uring the summer.

Conductivity of the water averages 500 µmhos/cm during the summer, ncreases in the fall, and reaches a maximum during the winter. Con- uctivity decreases during the spring when melt waters flush the eservoir. The pH of the reservoir averages 8.5 (Hanson 1978).

Summer thermal stratification is rare in the reservoir as winds

Fig. 1. Jamestown Reservoir



Buchanan Bridge
Bikini Bay
Walleye Point
Pelican Point
Smokey's Landing
Crappie Bay
Bullhead Bay
N. Tire Reef
Jim River Boat Club
S. Tire Reef
N
0
1
2
Kilometers

usually keep the reservoir water well mixed. Stratification may occur for a short time near the bottom in deeper waters after several calm days. Dissolved oxygen is usually uniformly distributed from top to bottom. Summer and winter kills of fish in the reservoir have not been reported (Gene Van Eeckhout, 1981, pers. comm.).

The Jamestown Reservoir is long and narrow and lies deep within the James River Valley. The reservoir is nearly straight and oriented north and south. This topography forms a natural wind tunnel and high waves can rapidly form when winds are blowing from either of these two directions. Bank erosion from wave action is a serious problem in the reservoir and contributes to the high turbidity levels.

Much of the bottom of the reservoir is composed of silt and organic muck. Some gravel and sand can be found in the southern portion of the reservoir. In certain areas, extensive shoreline deposits of soft shale and glacial boulders are found.

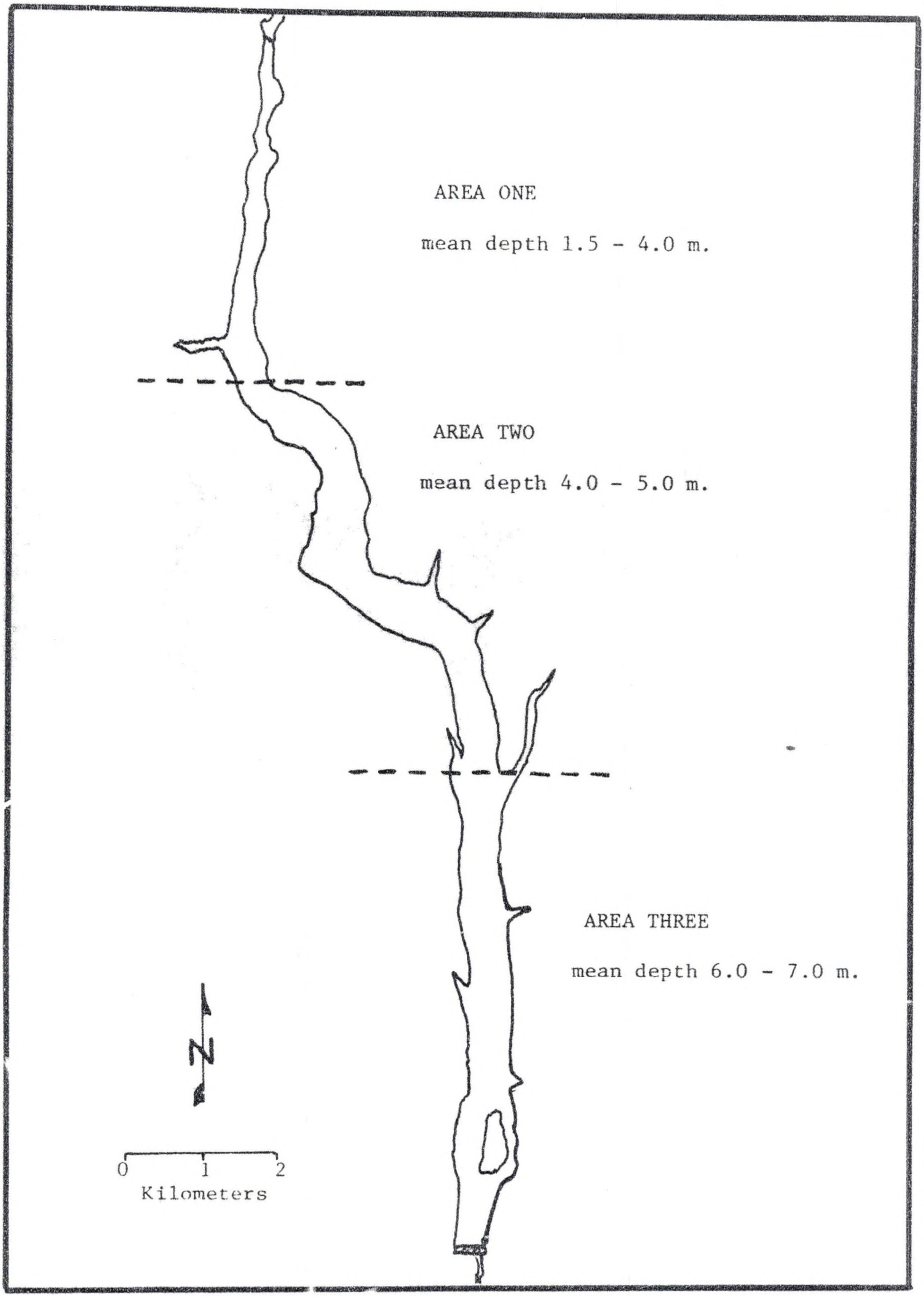
Northern pike, Esox lucius Linnaeus, smallmouth bass, Micropterus dolomieui Lacepede, and walleye are the leading predators found in the reservoir and provide most of the sport fishing. Other fish included in angler catches are: yellow perch, Perca flavescens (Mitchill), bluegill, Lepomis machrochirus Rafinesque, white crappie, Pomoxis annularis Rafinesque, and black crappie, P. nigromaculatus Lesueur. Non-sport fish include black bullhead, Ictalurus melas (Rafinesque), carp, Cyprinus carpio Linneaus, white sucker, Catostomus commersoni (Lacepede), and bigmouth buffalofish, Ictiobus cyprinellus (Valenciennes). Small forage species include fathead minnow, Pimephales promelas Rafinesque, and [illegible]tail shiner, Notropis hudsonius (Clinton). Black bullhead and carp are very abundant in the reservoir. Both smallmouth bass and spottail shiners have been introduced into the reservoir.

The reservoir can be arbitrarily divided into three sections based on depth, bottom and shoreline features, vegetation, and actual use by fish. The boundaries between these sections are not sharply defined, so that any change occurring within the reservoir would tend to shift the boundary lines.

The northern section, area one, extends from the bridge on Stutsman County Highway 42 (Buchanan bridge) to approximately 3.2 km north of Smokey's Landing (Fig. 2). This section is relatively shallow, with depths ranging from 1.5 to 4 m. Both submergent and emergent vegetation is present. An important habitat feature found in area one is the bulrush (Scripus sp.) capped submerged islands formed at normal pool and numerous submerged logs and brush piles. The major submergent aquatic vegetation occurring in this area is sago pondweed (Potamogeton pectinatus). This northern section is an excellent spawning area for fish requiring shallow vegetation for reproduction such as carp. However, no suitable walleye spawning habitat is found in the area or in other areas of the reservoir (Owen et al. 1981). Netting done in this area indicates that this section is also used as a nursery area by young of the year fish of several species (Steinwand 1982).

Area two of the reservoir extends southward from area one to approximately the Jim River Boat Club (Fig. 2). It can best be described as a transition between shallow and deep water habitats. The average depth is approximately 4 to 5 m. The major habitat feature in this area is the former river channel. The channel runs near the shoreline

Fig. 2. Major habitat divisions of Jamestown Reservoir


AREA ONE
mean depth 1.5 - 4.0 m.
AREA TWO
mean depth 4.0 - 5.0 m.
AREA THREE
mean depth 6.0 - 7.0 m.
N
0
1
2
Kilometers

through most of this section, providing easy access from deep water in the channel to shoreline feeding sites. Extensive mud flats are also found in this area. Much of the shoreline is composed of shale and some glacial till. There is little submergent or emergent aquatic vegetation, except within shallow bays.

Area three extends from the Jim River Boat Club to the dam (Fig. 2). It is the deepest section with depths averaging 6 to 7 m. The shoreline drops off rapidly into deep water and there is little littoral area. There is no submergent vegetation and emergent vegetation is sparse. An artificial tire reef was constructed in this section during 1980.

LITERATURE REVIEW

History of Tracking

Knowledge of fish movements and behavior has always been important to humans to satisfy both economic and scientific needs. Observing fish and other aquatic organisms is difficult due to the nature of the environment in which they reside.

Undoubtedly, surface visual observations were first used to study fish movement and behavior. Visual observation can provide useful information (Regier et al. 1969). However, this method is limited by light intensity, surface conditions, water clarity, depth, and is restricted to relatively short periods (Pitlo 1978). Observations made while SCUBA diving have the same limitations. In addition, the restricted movements of the diver and the inability to remain with the fish for extended periods limit the usefulness of this method for studying fish behavior (Ireland and Kanwisher 1978).

Hasler and Wisby (1958) attached floats to green sunfish, *Lepomis cyanellus* Rafinesque, in an attempt to follow the movements of fish from the surface. The position of the fish can be determined with great precision using this method. Line entanglement, exhaustion from towing, and unnatural restriction to the fish limits the usefulness of this method. Observations of the floats are restricted to daylight hours when visibility is good (Malinin and Svirskii 1973).

Traditional mark and recapture methods have been used in most studies of fish activity patterns (Konstantinov 1977). Tagging was first used in the United States in 1873 to learn the movements of atlantic salmon, Salmo salar Linnaeus, in the Penobscot River, Maine (Everhart et al. 1975). Since that time, mark and recapture has been used extensively throughout the world.

Four general methods of marking fish are described by Everhart et al. (1975). These methods are:

1) mutilation of body parts;

2) attachment, injection, or insertion of a foreign object or substance;

3) innoculation of parasites or bacteria;

4) injection of dyes or radioactive tracers.

Mark and recapture proves useful in determining general dispersal patterns, homing tendencies, movement rates and other behavioral information (Pitlo 1978). These methods are suitable for long term studies. However, mark and recapture is inadequate for determining short term changes in activity. No information is provided concerning diel activity patterns, path of movement, or environmental factors affecting movement (Bahr 1977). In addition, relatively large numbers of fish must be tagged to yield any statistically significant data. Success of tagging studies are mainly dependent on fisherman awareness and cooperation (Konstantinov 1977).

The advent of biotelemetry was a major advance in the study of wild animals and their behavior (Bahr 1977). Although biotelemetry has been used in medicine for a number of years, the application to animal research in the wild is fairly recent (Malinin and Svirskii 1973). The development of microelectronics and battery technology has led to the construction of miniature transmitters that can be carried by animals (Fryer 1974). Even though biotelemetric equipment is more expensive than simple marking tags, it becomes more cost effective than simple marking studies over the long run (Winter et al. 1978).

Biotelemetry is useful in a wide range of biological research. In addition to determining the physical location of a wild animal, biotelemetry used in conjunction with special sensors can transmit a wide variety of useful physiological and environmental parameters (Stasko and Pincock 1977). Two biotelemetry systems, radio and ultrasonic, are commonly used. These systems have been used to study many species of fish and marine mammals (Pincock and Luke 1979).

The first application of biotelemetry to wild animals was in 1954, when a radio transmitter was attached to a diseased woodchuck near Chambersburg, PA (Fisher 1976). The first attempts to apply biotelemetry to fishery problems met with little success (Bahr 1977). In the mid 1950's, the first successful use of underwater biotelemetry was made when adult coho salmon, Oncorhyncus kisutch (Walbaum), were tracked near Seattle, WA. Ultrasonic transmitters operating at 132 KHz were used. The salmon were tracked for several hours before the transmitters failed (Trefethen 1956). During 1957, 132 KHz ultrasonic transmitters were used to follow the movements of salmon as they approached the Bonneville Dam on the Columbia River (Johnson 1960).

Early attempts to use radio biotelemetry in aquatic studies failed. The use of radio was hampered by significant absorption of the electromagnetic radiation in water (Malinin and Svirskii 1973). In 1969, radio biotelemetry was successfully tested by the University of Minnesota's

Cedar Creek Bioelectronics Laboratory. Carp and northern pike were monitored in a small stream near Bethel, MN (Winter 1976).

Biotelemetric Systems

Choice of which system to use depends on many factors. For most applications, radio biotelemetry is the most suitable (Winter 1976). However, there are cases in which radio biotelemetry is unsuitable. Radio biotelemetry cannot be used in waters which have high conductivity or that are very deep. In such instances ultrasonic biotelemetry must be used (Stasko and Pincock 1977). When precise locational information is required, ultrasonic biotelemetry is of greater value than radio biotelemetry (Pincock and Luke 1979).

Advantages of radio biotelemetry were described by Winter et al. (1978). Those advantages discussed included:

1) inexpensive to build;

2) tracing can be done from boat, shore, or air;

3) long transmitter life;

4) range is not affected by fast moving water;

5) the same equipment can be used for other animals;

6) each transmitter can operate on a different frequency allowing more tags to be used without elaborate decoding procedures.

However, advancements in technology and a competitive market has increased the operating life while decreasing the cost of ultrasonic transmitters. These reasons have decreased the importance of some of the advantages of radio biotelemetry listed above (Don Brumbaugh, 1981, pers. comm.).

Ultrasonic Biotelemetry

Ultrasonic signals are acoustic compression waves at ultrasonic frequencies. The physics of ultrasonic wave propagation is the same as that for audible sound. A discussion of the principles of acoustic wave propagation in water is presented in Urick (1975). The frequency range useful for underwater biotelemetry is approximately 20-300 KHz (Stasko and Pincock 1977). Commercially built ultrasonic transmitters are limited by economics to frequencies between 50 and 100 KHz, with 74 KHz being the most common (Mitson 1978). However, selection of frequency must be based on technological requirements for a particular application.

Mitson (1978) gives two design considerations relating to selection of frequency. These considerations are range and transmitter size. There is a significant loss of signal due to absorption as frequency increases; thus, the audible range is decreased. Therefore, lower frequencies are more attractive. However, a limit imposed by the need for the transducer to operate at or near resonance increases the size of the transmitter (Stasko and Pincock 1977). Frequency choice must be a compromise between high output at high frequency or larger sized transmitters operating at low frequencies.

Detection of ultrasonic signals is determined by many factors. Range is influenced primarily by the spherical spreading loss of radiated energy and secondarily by loss due to the viscous nature of water (Brumbaugh 1980). Because sound travels faster in warmer water than cold, the ultrasonic signal will be refracted or bent away from warmer water layers. Thus, thermally stratified water will result in decreasing range (Mitson 1978). In certain cases, range will decrease due to particulate matter such as algae suspended in the water. Brumbaugh (1980) reports one case of a 98% reduction in range due to a heavy phyto-plankton bloom. Aquatic plants, bottom sediments, bottom topography, and surface noise (either natural or manmade) can all contribute to range reduction of ultrasonic signals (Stasko and Pincock 1977). In turbulent waters found in some rivers or near hydroelectric facilities, ultrasonic biotelemetry cannot be used (Schiefer and Power 1972). High waves can also produce noise which reduces reception range.

To detect ultrasonic signals underwater, a hydrophone is used. Hydrophones can range in complexity from simple directional hydrophones to sophisticated linear array hydrophones used to determine depth as well as direction (Gardella and Stasko 1974, Tesch 1976). Design of the hydrophones is important. Beam width, directionality, and sensitivity must all be considered in hydrophone design (Mitson 1978). Stasko and Pincock (1977) review the principles of hydrophone design. A more detailed treatment of the subject is given in Camp (1970).

Receivers take the input signal, filter and then amplify it, usually through an intermediate frequency, before passing it for final processing. Final processing of the signal can be made either electronically or by converting it to acoustic signals for listening (Stasko and Pincock 1977). Electronic processing produces a logic signal for automatic data processing. Receivers should be both portable and durable. Principles of receiver design is further discussed in Stasko and Pincock (1977).

Radio Biotelemetry

Radio biotelemetry uses electromagnetic radiation as a carrier wave. Radio signals attenuate rapidly in water and cannot be received underwater unless the antenna is very close to the transmitter (Stasko and Pincock 1977). Attenuation is exponentially increased with depth and salinity (Winter 1976). Reception range of the signal decreases as a result of this attenuation. At depths greater than 50 m (Stasko and Pincock 1977) or in conductivities greater than approximately 600 μmhos/cm (Larry Kuechle, 1980, pers. comm.), radio signals are unable to breakthrough the air-water interface. Methods used to calculate signal attenuation is given in Velle et al. (1979).

Attenuation due to increasing the depth of the transmitter results from characteristics of electromagnetic signal propagation underwater. Radio signals produced by the transmitter can only break through the air-water interface if they are less than 6.4 degrees from the vertical. Radio signals greater 6.4 degrees are reflected back by the surface of the water (Velle et al. 1979). Thus fewer signals reach the surface as the depth of the transmitter increases (Stasko and Pincock 1977). On entry into the air, the radio signals spread and are not normally subjected to further attenuation.

Frequencies used in radio biotelemetry range from 25 to 100 MHz (Winter et al. 1973). Winter et al. (1978) suggests that a frequency of 53 MHz travels better through water than those at higher frequencies. They also state that the advantages of lower frequencies are offset by the need for a bulkier receiving antenna. However, frequencies near 50 MHz are affected by sunspot activity and stratospheric skip may become a problem.

Attachment of Transmitters

The method of attaching biotelemetry transmitters to fish is important. There should be no adverse effects on posture, buoyancy, or locomotion; and also there should be no significant trauma produced (Fried et al. 1976). Any effects on behavior must also be considered (Shepherd 1973).

In general, there are two methods of attaching transmitters, externally on the back of the fish and internally either in the stomach or in the body cavity (Winter 1976). Japanese researchers have tried towable radio buoys on rainbow trout, Salmo gairdneri Richardson. However this method of attachment is very limited in usefulness (Kazihara 1972).

External attachment was the first method used to secure transmitters to fish (Johnson 1960). Transmitters have been attached by clamps (Trefethen 1956, Johnson 1960), by pins or wires through dorsal musculature (Bahr 1977), or by alligator clips (McCleave et al. 1967). External attachment is advantageous since it is fast and relatively simple. External attachment has been used in most studies using radio biotelemetry (Pitlo 1978). Transmitters attached externally to walleye have been used successfully in several studies (Holt et al. 1977, Bahr 1977). There are several disadvantages of external attachment. Movement of the transmitter may erode the tissue near the attachment site injuring the fish (Bahr 1977). The transmitter can become entangled in obstructions such as aquatic vegetation (Winter et al. 1978). Also the transmitter can affect behavior by increasing drag and cause bouyancy problems.

Transmitters have been forced down the esophagus into the stomach of the fish. This method is also generally quick and easy. However, the transmitter may be regurgitated by the fish (Hart and Summerfelt 1975). Insertion of the transmitter can rupture the esophagus (McCleave and Horrall 1970). Stomach placement of the transmitter may affect feeding in some species. Stasko and Pincock (1977) list species in which stomach placement of transmitters has been tried. Morris (1977) found that among 32 walleye with stomach placement of sham transmitters, 28 regurgitated the transmitters within 10 hours. He concluded that this method of transmitter attachment would be unsuitable for use in walleye biotelemetry studies.

Surgical implantation of transmitters into the body cavity of the fish has proved successful in several studies (Pitlo 1978, Dombeck 1979). Many of the disadvantages associated with attaching transmitters externally are eliminated by surgical implantation (Winter 1976). The problems of snagging and drag are avoided. Because the transmitter is placed nearer to the fish's center of gravity, bouyancy compensation is reduced. Also a larger transmitter package can be used than could normally be carried (Winter et al. 1978). Surgical implantation is not without its disadvantages. Initial trauma because of surgery may temporarily produce atypical behavior. This may be of little consequence in studies over several months (Stasko and Pincock 1977). Pitlo (1978) found that surgical implantation caused some mortality due to secondary infections of fungi. Time and the extra handling required increased stress to the fish, which may be disadvantageous depending on the species. However, Morris (1977) concluded that the advantages of internal attachment outweighed the disadvantages. He also felt that when the incision healed the transmitters were permanently retained. Thus it would seem that surgical attachment is the best method for most underwater biotelemetry applications. Surgical procedures have been described by Hart and Summerfelt (1975) and Bidgood (1980). Ager (1976), Pitlo (1978), and Einhouse (1981) successfully used surgical methods for attaching transmitters to walleyes.

Applications

Biotelemetric investigations of fish behavior, movement, and physiology have been conducted throughout the world. Biotelemetry has been especially useful in locational type studies. Locational studies have been classified by Stasko and Pincock (1977) into three general catagories: migration orientation, movements at obstructions, and ecology and behavior.

Biotelemetric studies have been conducted using specially equipped transmitters. Temperature preferences have been determined with temperature-sensing transmitters in a number of studies (Kelso 1976, Ross 1978). Pressure sensing transmitters have been used to determine swimming depths (Pincock and Luke 1975, Gray and Haynes 1977, Ross et al. 1979). EKG's of swimming fish have been measured both in the field and in the laboratory using biotelemetry (Lonsdale 1969, Pauley et al. 1979). Other special biotelemetric studies have measured illumination, swimming speed, compass orientation, opercular rates, and electrical brain activity (Stasko and Pincock 1977).

One of the first uses of biotelemetry was to study the migrational movements of fish (Johnson 1960). Since then many migrational studies have been made. Movements of sockeye salmon, Oncorhynchus nerka (Walbaum), have been studied in coastal waters (Stasko et al. 1976). The spawning migration of American shad, Alosa sapidissima (Wilson), has been studied in the Connecticut River (Dodson et al. 1972). However, biotelemetric techniques cannot provide a complete understanding of mechanisms of fish migrational orientation (Stasko et al. 1973).

Movements of fish at obstructions have been intensely studied in both the United States and the USSR. The movement of various species of salmon below dams has been studied by Monan and Liscom (1971), Johnson (1960), Malinin et al. (1970). The reaction of fish to thermal barriers created by power plans has been researched (Kelso 1974, Ross 1978). Net advoidance has been studied in American shad and bream, Abramis brama (Linnaeus), using ultrasonic biotelemetry (Malinin 1970, Leggett and Jones 1971). Poddubny (1969) found that sturgeon were temporarily disorientated when they passed under an electomagnetic field nerated by a high voltage electrical transmission line

Behavior and ecology of fishes has been studied employing biotelemetry in numerous cases. Winter (1976) studied the home range and movements of largemouth bass in Mary Lake, MN. He found that the indigenous bass established home ranges of 0.28 to 1.41 ha, but a bass that was introduced into Mary Lake from another lake did not establish a home range. Dombeck (1979) studied the seasonal movements of 18 muskellunge, Esox masquinongy Mitchill, tagged with radio transmitters. Their home range varied from 2.3 to 27.7 ha. He suggested that movements of prey species and temperature influenced home range size. Hart and Summerfelt (1973) found that flathead catfish, Pylodictis olivaris

(Rafinesque), established home ranges and also showed a degree of homing. Malinin (1970) found that northern pike and bream exhibited two distinct activity periods at dawn and dusk.

Systematics

The walleye is the largest member of the family Percidae in North America. Two subspecies of walleye are recognized, the yellow walleye, *Stizostedion vitreum vitreum* Mitchill, and the blue walleye, *S. v. glaucum* Hubbs, (Bailey et al. 1970). The blue walleye, also known as blue pike, was originally described as a separate species (Scott and Crossman 1973). Behavioral, physiological, morphological, and ecological differences led to the change to subspecific status (Scott and Crossman 1973). The blue walleye had an extremely restricted distribution (Trautman 1957) and is now either extinct or has been absorbed into the gene pool of *S. v. vitreum* (Regier et al. 1969). Four other species in the genus *Stizostedion* are known. The sauger, *S. canadense* (Smith), is another game fish found in North America. Three species are found in Europe and Asia, these are *S. lucioperca* (Linnaeus), *S. volgense* (Gmelin), and *S. marinum* (Cuvier) (Collette and Banarescu 1977).

Distribution

Distribution of the walleye is limited to freshwater and rarely, brackish water (Scott and Crossman 1973). It ranges from near the Arctic Coast in the MacKenzie River south-eastward through Quebec to the St. Lawrence River and southward to the Gulf Coast in Alabama (Colby et al. 1979). It has been widely introduced outside its native range, especially in western U.S. reservoirs and along the Atlantic Seaboard and elsewhere in North America (Collette and Banarescu 1977). The range of the walleye in North America follows closely the distributional patterns of the northern boreal forests and the central and southern hardwood forests (Colby et al. 1979).

Habitat

Walleyes show a preference for large, semi-turbid waters over much of its range (Scott and Crossman 1973, Johnson et al. 1977). It is tolerant of a great range of physical and chemical conditions with the possible exception of bright light (Colby et al. 1979). Walleyes do well in mesotrophic waters and less well in oligotrophic, early eutrophic, and advanced eutrophic environments (Regier et al. 1969). The temperature preference of walleye is 21-23°C, with the upper lethal limit of 31.6°C (Hokanson 1977).

Walleyes prefer a clean, hard substratum (Colby et al. 1979) and occur in the greatest abundance over gravel, bedrock, and other hard bottoms (Trautman 1957). Deep, organic bottoms are generally avoided, although they may be attracted to such areas if food resources are adequate (Harlan and Speaker 1969). Large rivers and streams, if sufficiently deep or turbid, are suitable habitat for walleye (Cassity 1979).

Depth distribution of walleye varies, and depends on illumination level, turbidity, and type of shelter areas available (Ryder 1977). Within clear lakes, light is the most important variable determining depth distribution. Walleyes have been reported to select depths that were above preferred temperatures but which provided better shelter from light (Scott and Crossman 1973).

Foods and Feeding

During the first six weeks of life, walleyes are dependent on small inverebrates for food. The bulk of this diet consists mainly of copepods, cladocerans, rotifers, and chironomid larvae (Cassity 1979). Bulkley et al. (1976) found that walleye fry in Clear Lake, IA feed initially upon larger zooplankters, especially the cladoceran Daphnia, even though rotifers and copepod nauplii were abundant.

Walleyes shift from zooplankton and small inverebrates to fishes after they reach a certain size. Dobie (1966), cited by Colby et al. (1979), reported that a shift to feeding on fish was made when they reached a length of 30 mm. However, small forage fish were not important in their diet until the walleyes were 75-106 mm long (Priegel 1969, Walker and Applegate 1976). Young of the year (YOY) yellow perch are often the principle prey of YOY walleyes (Ney 1978). When abundant, other species are important as food items. Cannibalism sometimes occurs among walleye. Chevalier (1973) found that cannabalism by adults on YOY walleye in Onedia Lake, NY was a major factor limiting the size of year classes. Forney (1974) found that cannabalism was reduced in Lake Onedia when YOY perch were abundant.

Adult walleye are opportunistic, preying on a large selection of forage fish. In some populations, mayflies and chironmids are seasonally important (Swenson 1977). Young of the year yellow perch are often the major food item, but this may be a reflection of availability rather than actual selection (Ney 1978). Walleye in Lake Michigan ignored abundant yellow perch in favor of larger alewife, Alosa pseudoharengus

(Wilson), and rainbow smelt, Osmerus mordax (Mitchill) (Wagner 1972). Within North Dakota, walleyes are known to feed on many different species. Berard (1978) found that rainbow smelt comprised 50% of items found in Lake Sakakawea walleye during the spring. In the Jamestown Reservoir, walleyes have been sampled with the remains of black bullhead and crayfish as well as yellow perch (Aadland 1982).

Walleye feeding in clear lakes is either crepuscular or nocturnal (Carlander and Cleary 1949, Ryder 1977, Swenson 1977). Diel movements from deeper water into the shallows to feed can occur prior to the approach of storms or during strong winds (Colby et al. 1979). In turbid waters, walleyes may feed throughout the day (Scott and Crossman 1973). Walleyes rely primarily on vision rather than tactile or olfactory senses in searching for food (Disler and Smirnov 1977).

Reproduction

Walleyes spawn in the spring shortly after ice break up (Scott and Crossman 1973). The temperature at which spawning occurs ranges from 5.6-11.1°C. Colby et al. (1979) state that spawning temperatures appear to be a function of the thermal history and the maturation state of the walleye stock.

Spawning occurs in shallow water usually over gravel or broken rock. Other bottom types may be used provided that there is sufficient water movement or exchange of oxygen. In eutrophic waters, lack of suitable spawning habitat seems to be a significant factor limiting walleye populations (Colby et al. 1979). Eggs are randomly scattered over the bottom and there is no parental care. Walleye reproduction is reviewed in Colby et al. (1979).

Movements to spawning grounds have been described by various authors (Eschmeyer 1950, Crowe 1962, Ferguson and Derksen 1971). Homing behavior has been reported by Crowe (1962), Olson and Scidmore (1962), Ryder (1968), and Spangler et al. (1977). Walleyes spawning in rivers move up stream to spawning areas, lake spawning walleyes will generally move to inshore spawning sites (Colby et al. 1979). The distance of movements to spawning grounds are usually less than 16 km, but walleyes have been found to make homing movements in excess of 200 km in certain waters (Wolfert 1963, Ferguson and Derksen 1971). The environmental suitability of the habitat is primarily responsible for the distances traversed (Colby et al. 1979).

Activity Areas

Walleyes establish summer activity areas or home ranges (Ager 1976, Pitlo 1978). The size of these areas vary and tend to increase in size during the winter (Ager 1976). In several biotelemetric studies of walleye in rivers, no home range was established (Fossum 1975, Bahr 1977). The distance moved by individuals may be influenced by the seasonal availability of food (Harlan and Speaker 1969). The reason for the formation of activity areas has not been fully determined.

MATERIALS AND METHODS

Capture and Handling

Walleyes were collected in frame nets (modified fyke) and experimental gill nets. Two types of frame nets were used, 0.9 x 1.2 m nets and 1.2 x 1.8 m nets. Experimental gill nets were 38.1 by 1.8 m with five panels of varying mesh size. Gill net sets were checked at 45 minute intervals to reduce stress and possible injury or death to the fish. Walleye weighing over 1 kg were used for transmitter implantation. This was to maintain a high body weight to transmitter weight ratio. Upon removal from the net, the fish were placed into an aerated livewell for transport to the site of surgery.

Surgery

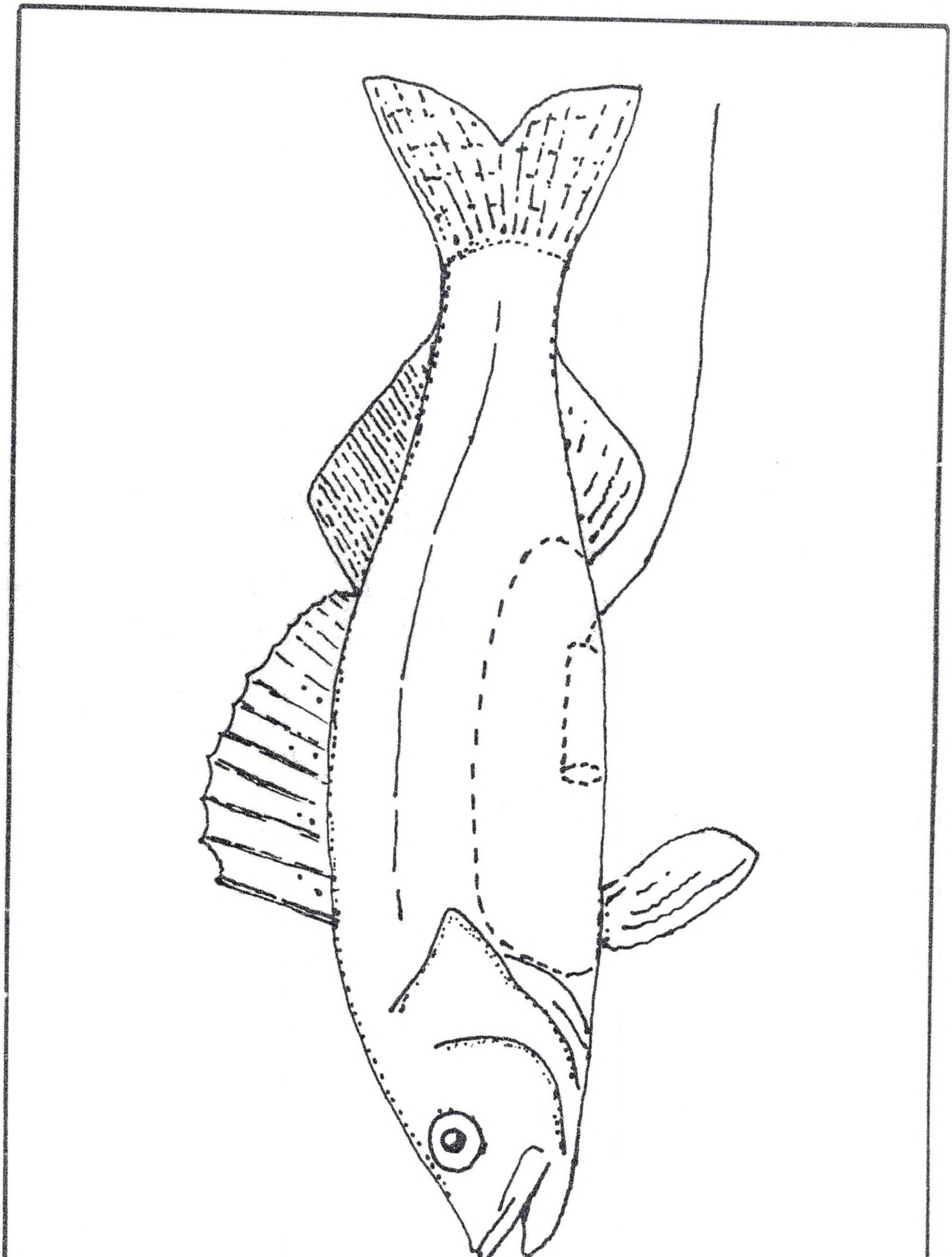
Surgical implantation was used to attach the transmitters. In 1980, fish were anesthetized with a mixture of 35 ppm MS-222 and 10 ppm Quinaldine introduced into the livewell. In 1981, a mixture of 15 ppm MS-222 and 10 ppm Quinaldine was used. The concentration of the anesthetic mixture was determined experimentally prior to actual implantation of transmitters. The fish were deemed ready for surgery when they lost equilibrium and failed to respond to stimulus. The fish usually were anesthetized in less than five minutes.

The walleye were placed on their backs in a specially constructed V-shaped trough resting in a tank of water taken from the reservoir. The fish were positioned with their head underwater and their ventral surface above water. The incision site was wiped with sterile guaze soaked with a normal saline solution to prevent the introduction of non sterile water or debris into the incision. Often the abdomen of the walleye would have small algal growths on the surface.

During 1980, we controlled the degree of anesthesia during surgery by placing two plastic tubes into the mouth of the walleye being operated on. One tube supplied water mixed with the anesthetic and the other supplied fresh lake water. Regulation of the flow in each tube maintained the desired state of anesthesia throughout the surgery. This method was not used in 1981 because it required one extra assistant. In 1981, if the walleye started to revive during surgery, additional anesthetic was introduced directly into the tank.

The incision was made on the abdomen approximately 20 mm off the mid line and 50 mm from the urogentital opening. The incision was from 40 to 60 mm long, and was made as small as possible depending on the type of transmitter. Radio transmitters required a slightly larger incision than ultrasonic transmitters because the external antenna needed to be threaded through the abdominal wall. Figure 3 shows the relative position of the radio transmitter and antenna within the body cavity. A protected tube technique was used to protect viscera from accidental puncture while threading the antenna. An antibiotic, oxytetracycline, was administered at a dose rate of 5 cc per kilogram of body weight prior to closing the incision. The antibiotic was given as a prophylactic measure against possible bacterial infections. The incision was closed with a 3/4 curved atraumatic cutting needle trailing 00 nylon suture. A continuous mattress stitch tied off with a square knot was employed.

Fig. 3. Radio transmitter in place in body cavity with antenna extending through body wall



Post operative care and handling

Upon completion of surgery the walleyes were weighed, measured, and scale samples taken for aging. Walleyes in 1980 were also externally tagged with Floy tags to aid in identification if recaptured. This practice was discontinued in 1981.

In 1980, the walleyes were placed in holding cribs for 24 hours for observation before they were released. If they appeared healthy they were then transported to where they were captured and released. Handling methods were changed in 1981. After surgery the walleyes were resuscitated and immediately released at the surgery site. This change was made to prevent additional stress to the fish.

Radio Biotelemetric Equipment

During 1980, radio biotelemetry was used. The transmitters were designed and built by the University of Minnesota's Cedar Creek Bioelectronics Laboratory, Bethel, MN. The radio transmitters were designed to operate at frequencies between 53 and 54 MHz. Individual transmitters in each fish were recognized by the specific frequency assigned to each transmitter. These individual frequencies were separated from each other by at least 20KHz. The transmitters also pulsed at a rate of approximately one beat per second. This conserved battery life and made the signals easier to hear.

Radio transmitters were cylindrically shaped with a diameter of approximately 0.75 cm and were 2.5 cm long. A 5.3 cm teflon coated external whip antenna projected from one end of the transmitter. The transmitter weight was approximately 30 g in the air. Lithium batteries were used to power the transmitters. The transmitter circuitry and battery were potted in epoxy to seal it from water. A magnetic reed switch activated the transmitters. Projected transmitter life was four to five months.

The receiving system consisted of a portable receiver, a yagi antenna, and a hand held loop antenna. The receiver, also constructed by Cedar Creek Bioelectronics Lab., was designed to select frequencies to the nearest kilohertz. A signal strength meter incorporated into the receiver aided in determining signal direction. A 3.7 m, five element yagi antenna was used to detect signals at ranges greater than 100 m. The yagi antenna was mounted to the floor of the boat by a 3 m metal mast. A diamond shape bidirectional hand held loop antenna was used for precise location of fish position at ranges under 100 m.

Tracking of radio tagged walleye was primarily accomplished by boat. An unscheduled tracking scheme was used to allow searching during both day and night hours. Typically, searching was initiated at the last recorded position of the fish. On a few occasions tracking was done on shore. Initial searching for a signal was made by using the yagi antenna. By zig-zagging the boat from shore to shore while sweeping the yagi antenna in a 360 degree arc, complete coverage of an area could be made in a relatively short time. Upon reception of a radio signal the general direction of the fish was determined and the boat moved toward the signal. When it was felt that the boat was within 100 m of the fish, the hand held loop antenna was used. The null signal, perpendicular to plane of the antenna, was used to determine the direction to the fish. The boat was in position over the walleye when the signal became omnidirectional.

When the fish was located a buoy was dropped to mark the position. Time, temperature, cloud cover, wind speed and direction, and depth were recorded at each reading. Depth, bottom features, and the presence of fish was determined using a Lowrance model 1510B graph unit. Fish depth was made on the assumption that the walleye would be on or within one meter from the bottom, unless graph recordings indicated suspended fish. The position of the fish was recorded by taking bearings from at least two established shoreline landmarks using a Silva type 15T compass. The compass bearings of the fish's position were later transferred to a map.

Ultrasonic biotelemetric equipment

In 1981, ultrasonic biotelemetry was used to track walleye. The transmitters, hydrophones, and receivers were constructed by Don Brumbaugh of Tucson, Arizona.

The ultrasonic transmitters were 16 mm in diameter and 60 mm long. The transmitters weighed 20 g in the air and 8 g in water. The operation frequency was at or near 75 KHz. Identification of individual transmitters was based primarily on pulse rate and secondarily on frequency. Expected operating life of the transmitters was approximately 18 months. The transmitters were sealed within a plastic cylinder with the open end sealed by wax. The transmitters were activated by the manufacturer prior to being shipped.

The receiving system consisted of a directional hydrophone and a digital readout ultrasonic receiver. The hydrophones had a sensitivity of -84 dBv re 1.0 μBar, and a beam width of +6.0 degrees at half power points. A tiltable mounting bracket from an electric trolling motor was used to secure the hydrophone shaft to the boat used for tracking. This hydrophone assembly allowed the operator to quickly raise or lower it from the water. The receiver had an internal pulse counter which displayed the pulse rate of the transmitter on a LCD. This feature was very useful for rapid identification of the transmitter. In addition to the pulse counter, the frequency could be tuned to the nearest tenth of a kilohertz for additional identification.

Ultrasonic tracking methodology differed from radio biotelemetric tracking. To receive ultrasonic signals, the boat had to be stopped in the water with the outboard motor shut off. Tracking was therefore accomplished by making stops at intervals approximately 100 to 150 m apart. At each listening stop the hydrophone was swept 360 degrees to cover the entire area. When contact with a fish was made, the position of the boat relative to two shoreline landmarks and the direction of the fish was made using a compass. The boat was then moved to a new position approximately perpendicular to the last position and new shoreline readings were taken. This triangulation method proved to be time consuming and if the fish moved between readings erroneous locations would be made. With increased familiarity of the receiving equipment it was possible to position the boat within approximately 5 m of the fish and take bearings on fixed shoreline points to establish the fish's location. Data were recorded at each positional fix in the same fashion as they were recorded for radio tracking.

Terminology

A discrete area that the fish repeatedly utilized during a period of at least several weeks was defined as an activity area. The dimensions of activity areas were outlined by plotting locational points on a map and then connecting the outermost plots as described by Winter (1976). If the boundary of the polygon crossed land then the shoreline was used as a boundary. The surface area of the activity area was found using a planimeter.

As suggested by Winter (1976), obvious wanderings from the activity area were excluded from the calculations of activity area. These types of movements were termed "exploratory excursions."

RESULTS

Radio Tracking

Four walleyes ranging in weight from 1.7 to 4.4 kg were implanted with radio transmitters during the summer of 1980. Table 1 provides physical characteristics of these walleyes. Attempts were made to track the fish from 3 July to 8 August and during weekends in September. One walleye was tracked for approximately a 2.5 week period. The remaining three walleyes were never relocated.

Table 1. Physical characteristics of walleyes implanted with radio transmitters in 1980.

Fish ID	length (mm)	weight (g)	age	sex	date captured	days tracked	No. fixes	last contact
140	631	1770	5	F	2 Jul.	15	24	18 Jul.
280	631	2359	6	F	2 Jul.	-	-	-
240	747	4450	7	F	6 Aug.	1	1	7 Aug.
480	648	3175	6	F	7 Aug.	-	-	-

The first two walleyes, numbers 140 and 280, were captured in a frame net set near Bikini Point on 2 July 1980. Radios were implanted at Smokey's Landing and the fish were held overnight for observation. They were released at the point of capture the following day. Walleye number 140 was contacted 3 July and followed for a total of 15 days thereafter (Table 1). Walleye number 280 could not be contacted.

Walleye 240 was captured in a gill net on 6 August and taken to Smokey's Landing for surgery. It was released from the holding net at 2030 hours of the same day. The fourth walleye, no. 480, was taken in a gill net on 7 August. Surgery was accomplished at Smokey's Landing and the fish was released at the point of capture the following day.

Except for the readings taken immediately after being released, contact with walleyes 240, 280, and 480 was never re-established. The fate of these walleyes is unknown.

Movements of Walleye 140

This fish was tracked from 3 July to 18 July 1980. During this time the walleye remained near the site of its capture (Fig. 4). Activity area size of this walleye was 49.4 ha. The walleye's average depth distribution was 2.3 m.

Regular daily movement pattern within the activity area was found for this fish. During the day, walleye 140 moved to the north into shallow water. This general northward trend would continue until evening, when the fish reached the northern limits of its activity area. In the evening, from 1800 hours until sunset the fish was often found resting (remaining motionless). The walleye moved south during the night and by sunrise it would be at the southern limits of its activity area. Daily movement rates averaged 279 m/hr. This is not to suggest that movement was continuous, rather movement was in a stop and go manner. The timing, length of individual movements, and distance traversed varied. Figure 5 shows typical daily movements made by walleye 140.

Contact with fish 140 was lost after 18 July and wasn't resumed until 29 July. It was then located in shallow water approximately 1.5 km

Fig. 4. Activity area of Walleye 140 from 3 July to 15 July, 1980. The River channel is shown on this and subsequent maps. ----

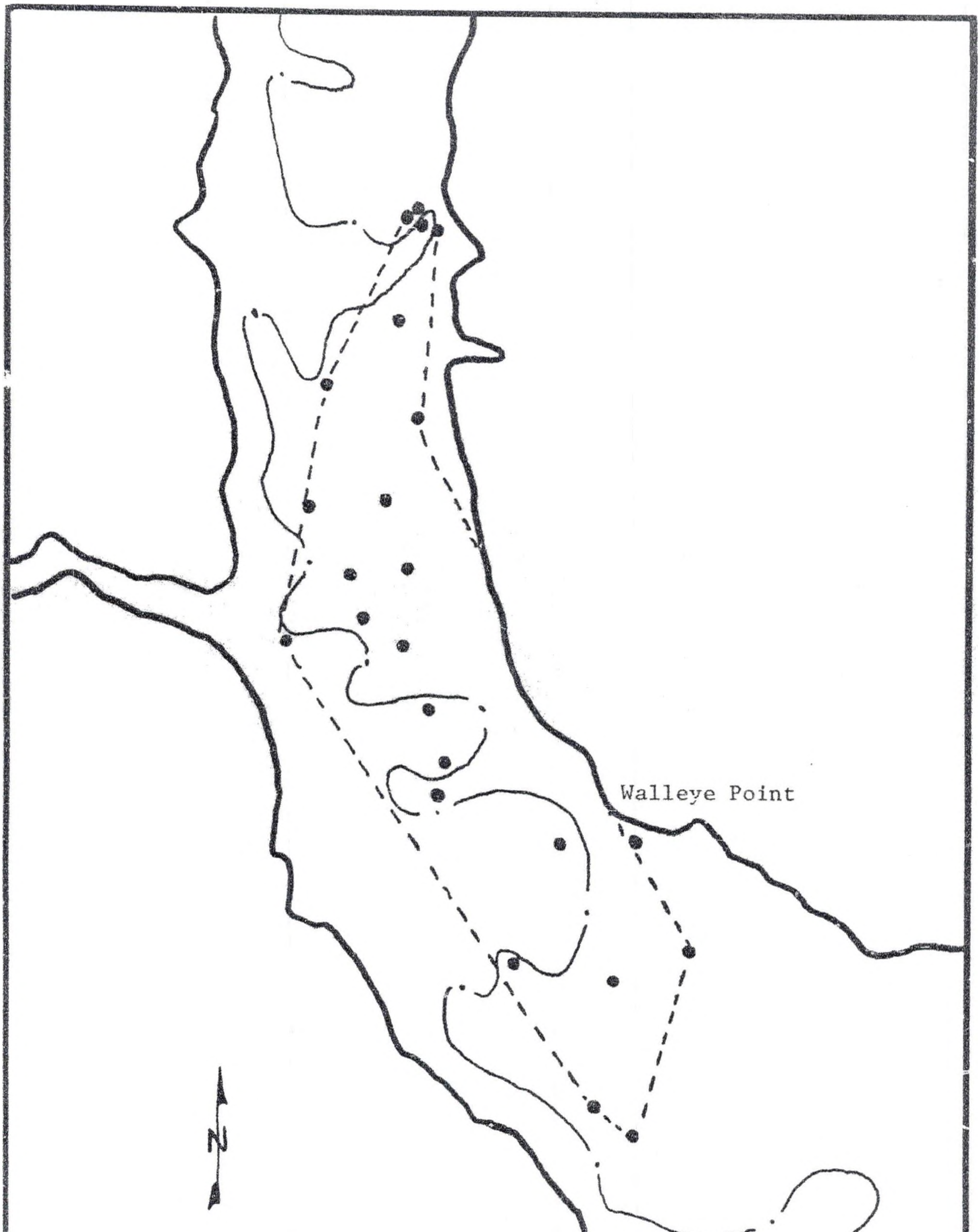
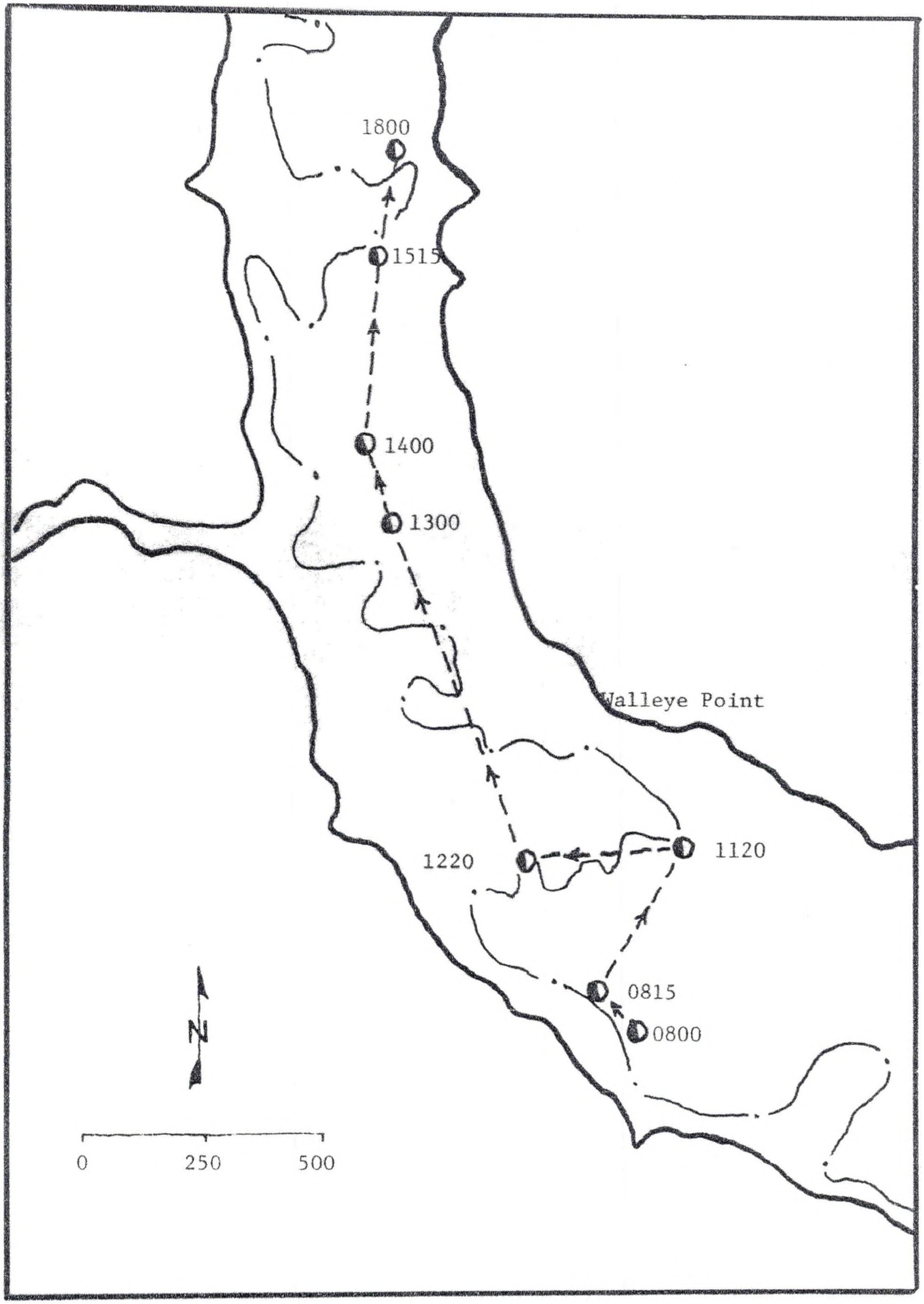

Walleye Point
N
0
250
500
meters

Fig. 5. Daily movements of walleye 140 on 10 July, 1980


1800
1515
1400
1300
Walleye Point
1220
1120
0815
0800
N
0
250
500

south of Buchanan Bridge. The position of the fish did not change during the next several days and it was then assumed that the walleye had either died or the transmitter had been shed. The transmitter was still operating in late September when the last check was made. No attempt was made to recover the transmitter due to the turbidity of the water.

Ultrasonic Tracking

In 1981, eight walleyes were implanted with ultrasonic transmitters. These walleyes ranged in weight from 2.2 to 4.2 kg. One walleye died a few days after surgery and the transmitter was recovered. Seven walleyes were successfully tracked throughout the summer. The period of tracking lasted from 18 May to 2 September. The physical data for these walleye are given in Table 2.

Individual Activity Patterns

Fish 523

This 2.9 kg female was captured 21 May on the west shore north of Pelican Point. The walleye was taken to Smokey's Landing, a transmitter was implanted and it was released there. The fish was first located 27 May near the mouth of Crappie Bay. During June and the first half of July this fish established a 17.6 ha activity area near the Pelican Point area (Fig. 6). It abandoned this area in mid-July and became nomadic. On 14 July, the walleye was found near the Bullhead Bay area. It remained in this area for approximately two weeks, although very few readings were taken. By 10 August the fish had moved south to an area near the south tire reef. The fish continued to move south

Table 2. Physical characteristics of walleyes implanted with ultrasonic transmitters in 1981.

Fish ID	length (mm)	weight (g)	age	sex	date captured	days tracked	no. fixes	last contact
695[a]	-	-	-	-	15 May	95	42	17 Aug.
845	630	2500	-	F	15 May	109	54	1 Sept.
523	720	2900	7	F	21 May	89	39	17 Aug.
1500	675	2890	6	F	21 May	89	56	17 Aug.
1080	565	1640	5	M	28 May	75	47	12 Aug.
1221	744	4240	7	-	28 May	80	25	17 Aug.
1450	610	2210	6	F	28 May	96	63	1 Sept.
1150[b]	720	3405	7	-	14 Jul.	-	-	-

[a] fish accidentally released before data collected.

[b] fish died within three days after being released.

for the next two days (Fig. 7). The last contact with the walleye was on 17 August. On this date the fish was located in the river channel near Walleye Point. Between 12 August and 17 August the fish had moved approximately 8 km.

Fish 695

This walleye was captured 15 May 1981 near walleye point. A transmitter was implanted at Smokey's Landing and the fish was released. It was first relocated in the mouth of Crappie Bay on 19 May. During June it occupied the area north of Smokey's Landing near Pelican Point. Throughout July and August this fish gradually moved southward, eventually

Fig. 6. Activity area of walleye 523 during June and July 1981

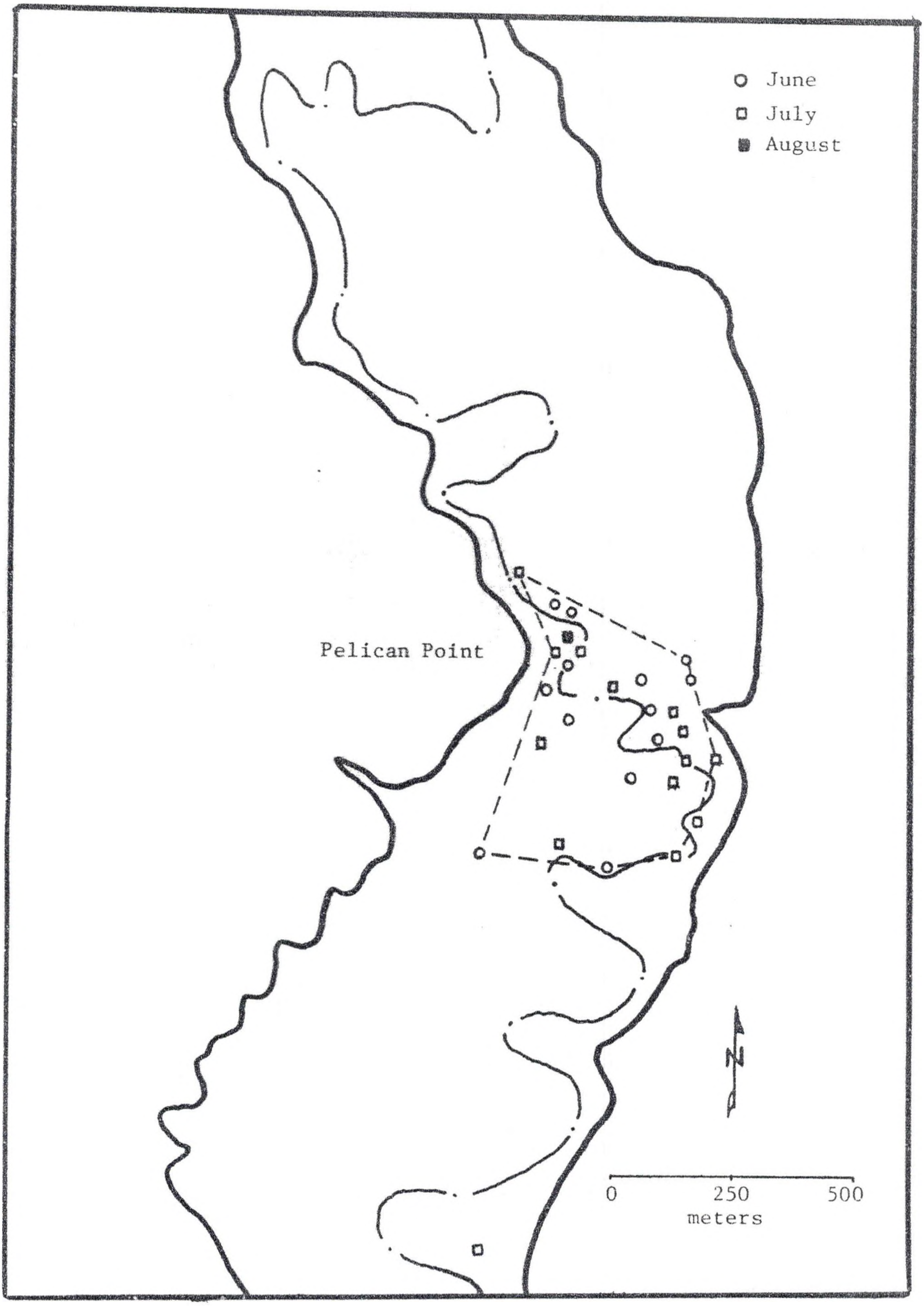
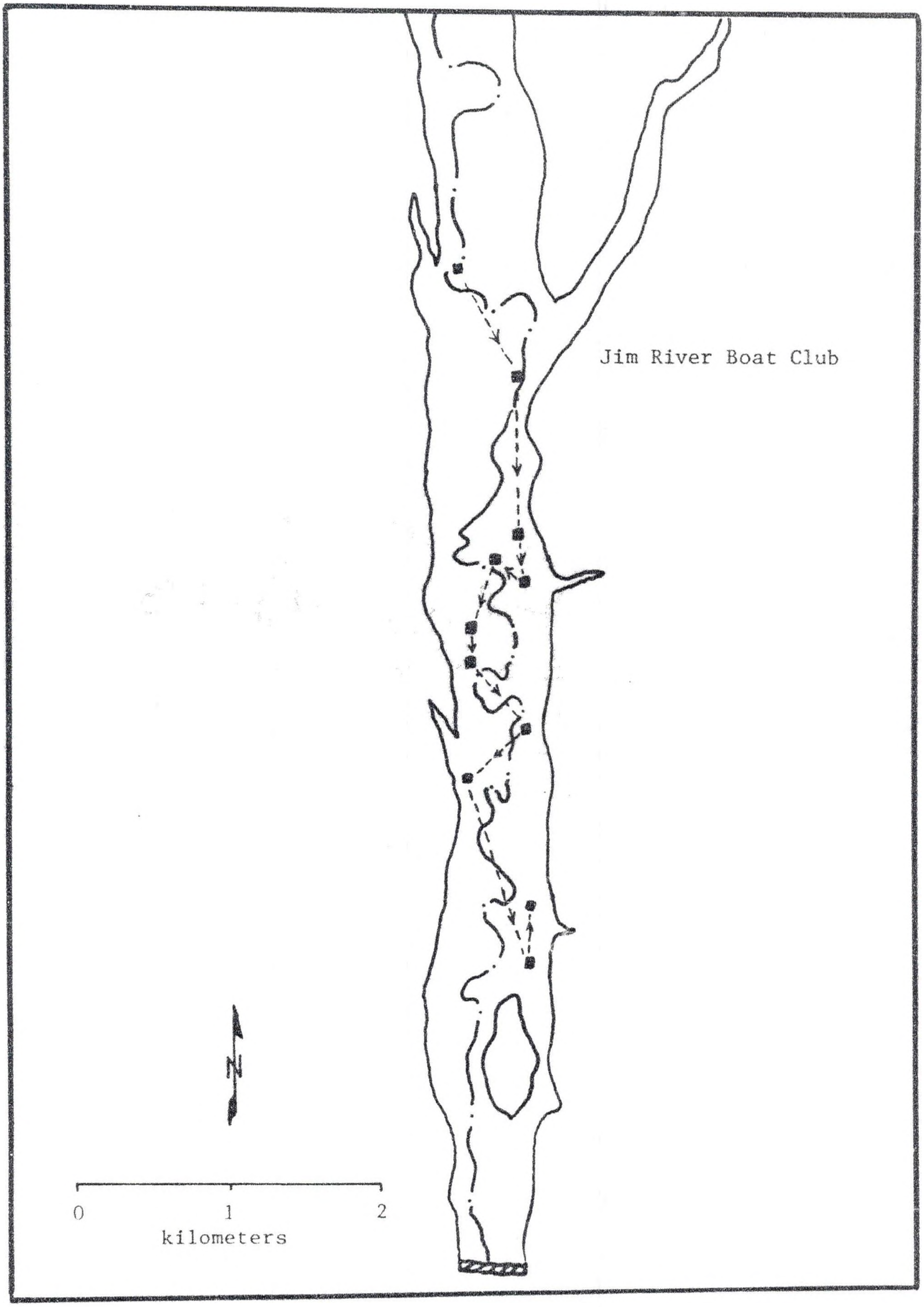

○ June
□ July
■ August
Pelican Point
N
0
250
500
meters

Fig. 7. Exploratory excursions made by walleye 523 in August 1981


Jim River Boat Club
N
0
1
2
kilometers

reaching the face of the dam by mid-August (Figs. 8-9). Fish 695 failed to establish any activity center and was nomadic throughout the summer. Its movements were progressively toward deeper water. During the study period, this fish moved the greatest distance from its capture point and occupied the deepest water of any of the fish monitored.

Fish 845

This female was captured on 15 May with fish 695. It was released at Smokey's Landing following surgery. She was first relocated 19 May near the site of her capture. The walleye established an activity area 67.3 ha in size near Pelican Point (Fig. 10). The walleye made extensive use of the former river channel when moving. It was never found to make any excursions away from its activity center.

Fish 1080

This male was captured 28 May north of Walleye Point. A transmitter was implanted and it was released at Smokey's Landing. Contact was first made with this fish on 2 June. It established an activity area of 74.5 ha between Smokey's Landing and Walleye Point, which was the largest area found during the study (Fig. 11). Average locational depth during the study period was 4.7 m.

Fish 1150

On 14 July, a 3.4 kg walleye was captured in a gill net and brought to Smokey's Landing. Surgery was performed and the fish was released. However, the fish had difficulty in gaining its equilibrium. It finally moved into approximately 3.5 m of water. For the next three days the

Fig. 8. Locations of walleye 695 during June and July 1981

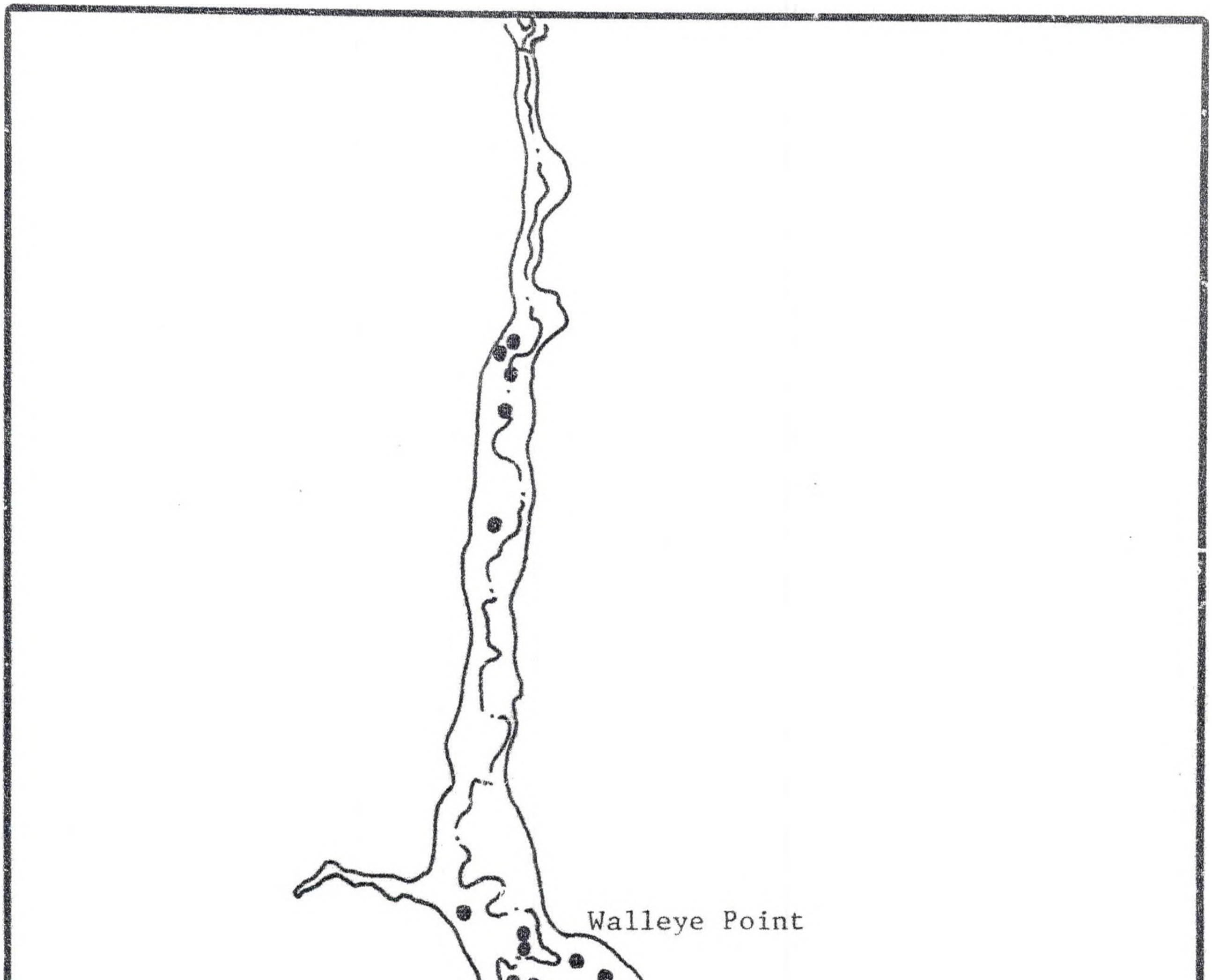

Walleye Point
Pelican Point
Crappie Bay
N
0
1
2
kilometers

Fig. 9. Locations of walleye 695 during August 1981

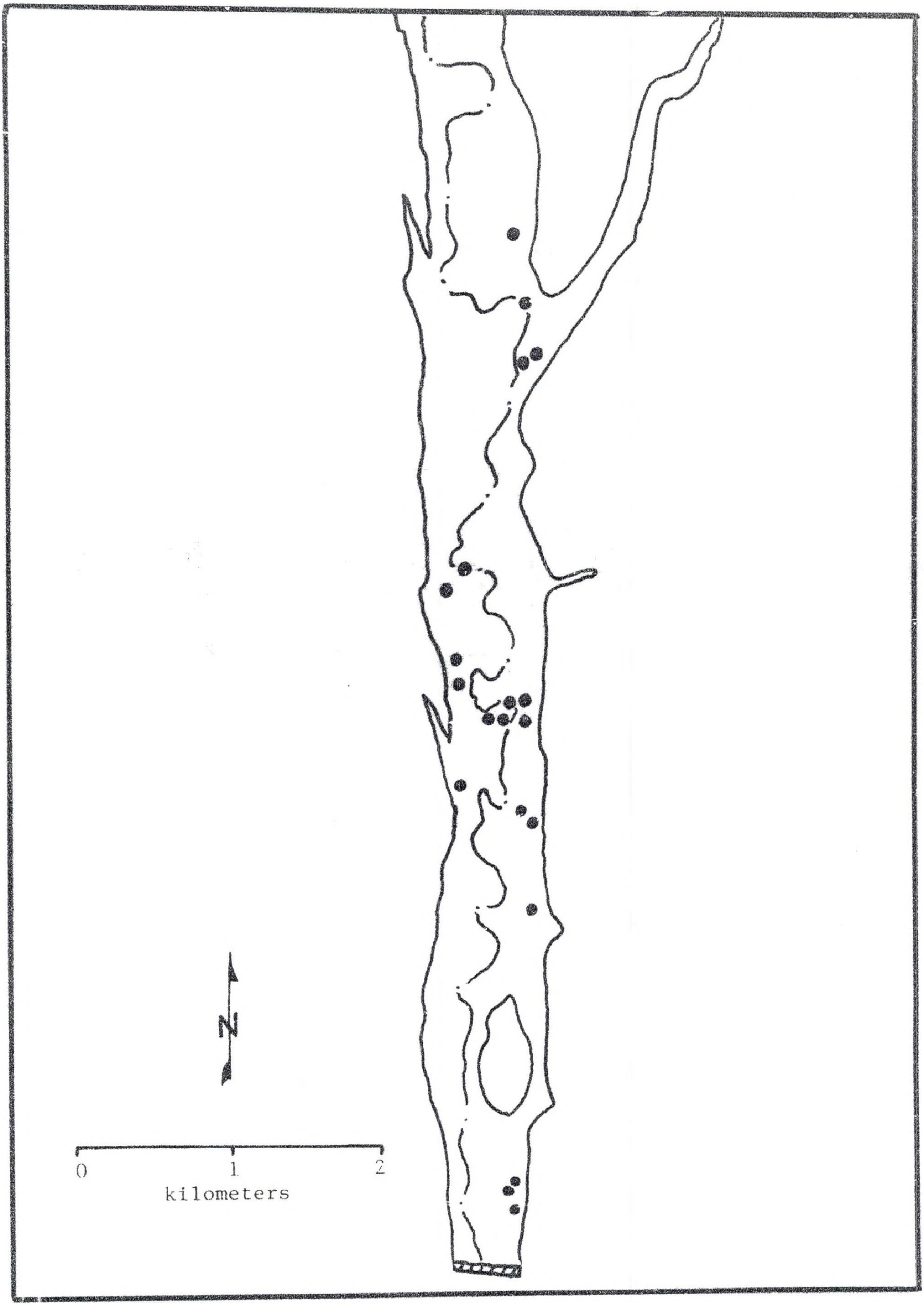

N
0
1
2
kilometers

Fig. 10. Activity area of walleye 845 during June to August 1981

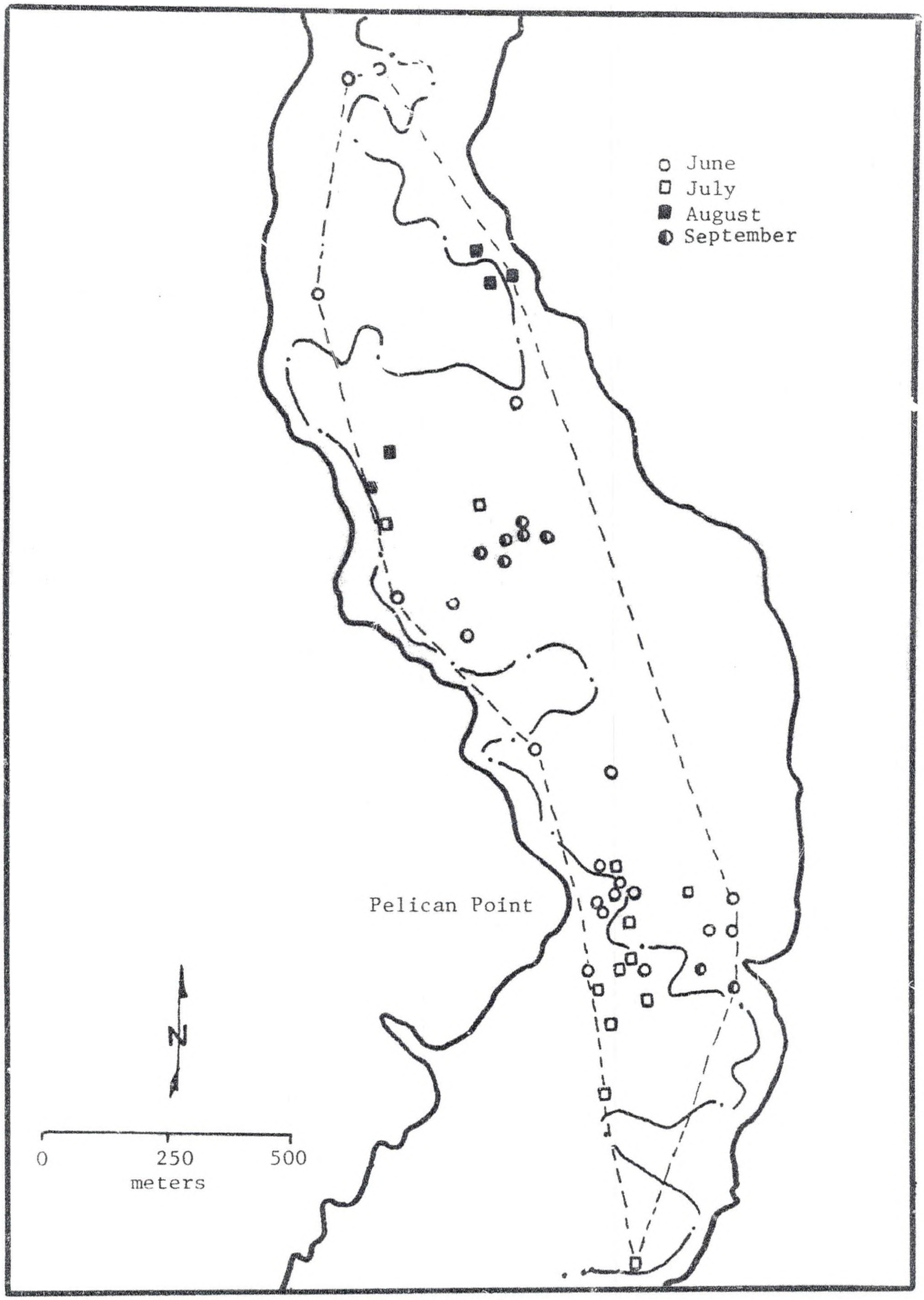
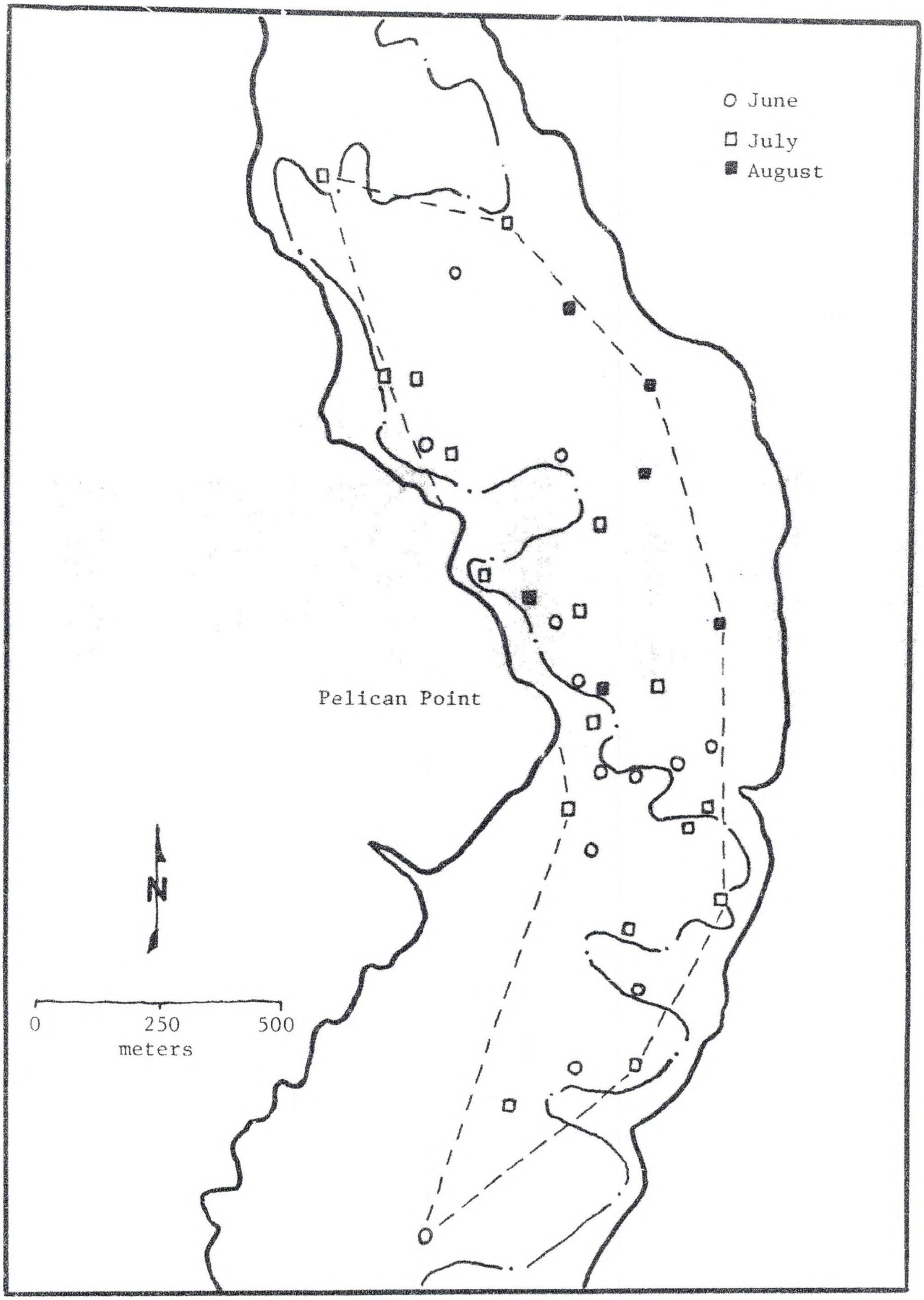

○ June
□ July
■ August
◐ September
Pelican Point
N
0
250
500
meters

Fig. 11. Activity area of walleye 1080 during June to August 1981


○ June
□ July
■ August
Pelican Point
N
0
250
500
meters

fish remained in the area, moving very little. Contact with the fish was lost for a week and then it was found dead on the shore.

Fish 1221

This fish was captured 28 May slightly north of Walleye Point. The transmitter was implanted at Smokey's Landing and the fish was released there. This fish was followed as it moved from the point of release. It followed the west shore in approximately 2.5 m of water directly to the area where it was captured within two hours after release (Fig. 12). During the first week of June it was making daily movements to a feeding area 2.5 km north of its capture site. By 11 June the walleye was utilizing the area near Pelican Point. It remained in the Pelican Point area until late June (Fig. 13). However, few readings were taken during this time due to weather and inability to consistently locate this walleye. On 9 July it was located near the Jim River Boat Club and remained in that area during July and into the first week of August (Fig. 14). From 10 to 12 August the fish made an excursion to south tire reef area. It was during this excursion that the fish occupied the deepest water, averaging 8.5 m. By 14 August, the fish had returned to the area near the Jim River Boat Club. No calculation of activity area was possible due to the low number of fixes and the extensive movements made by this walleye.

Fish 1450

This fish was captured 28 May, transported to Smokey's Landing for surgery and released there. Contact was first made on 1 June, when it was found moving northward, approximately 1 km north of Pelican Point.

Fig. 12. Homing of walleye 1221 to capture site after being released. The time of fish location is expressed in military time.

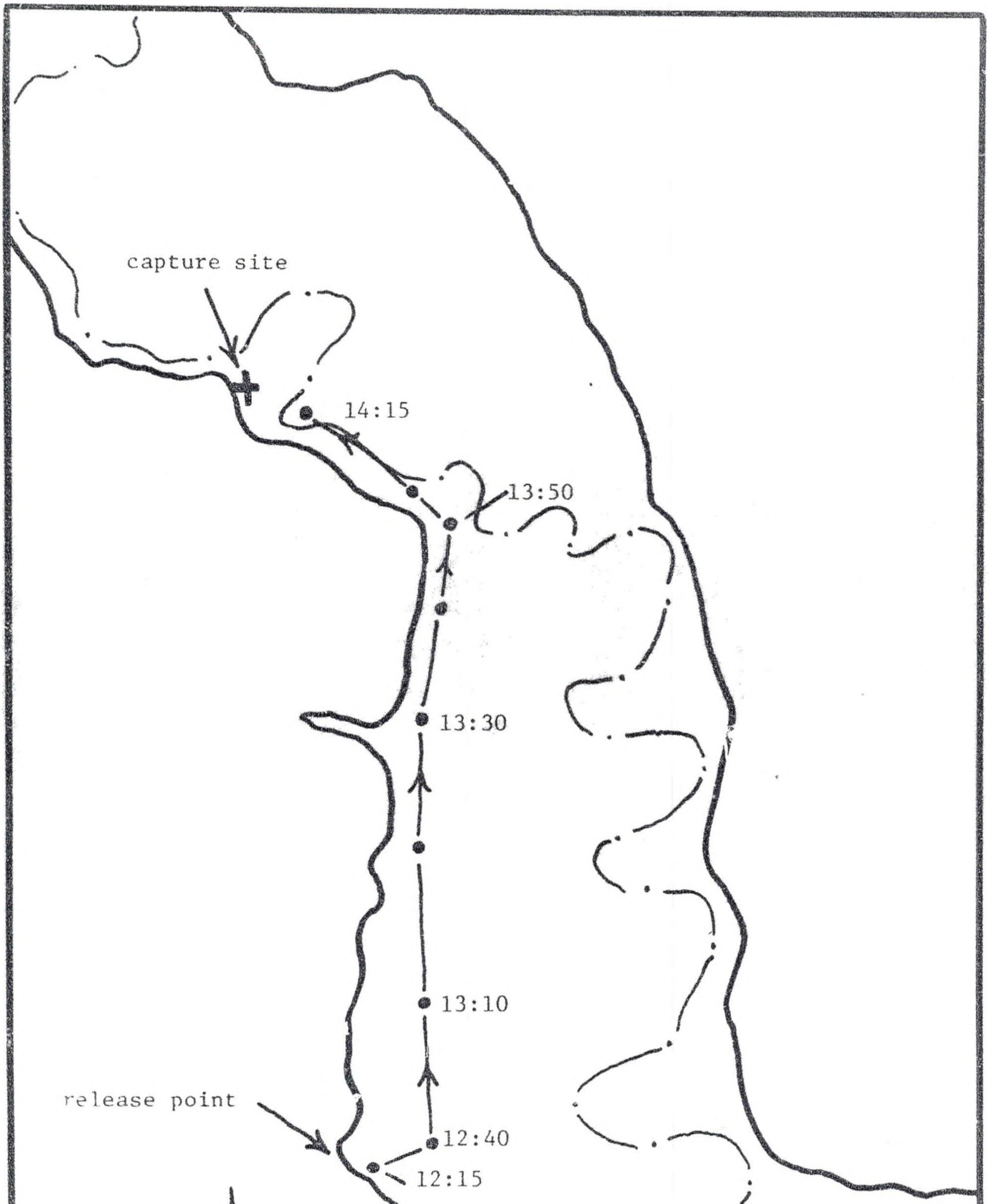

capture site
14:15
13:50
13:30
13:10
release point
12:40
12:15
N
0
250
500
meters

Fig. 13. Locations of walleye 1221 during June and July 1981

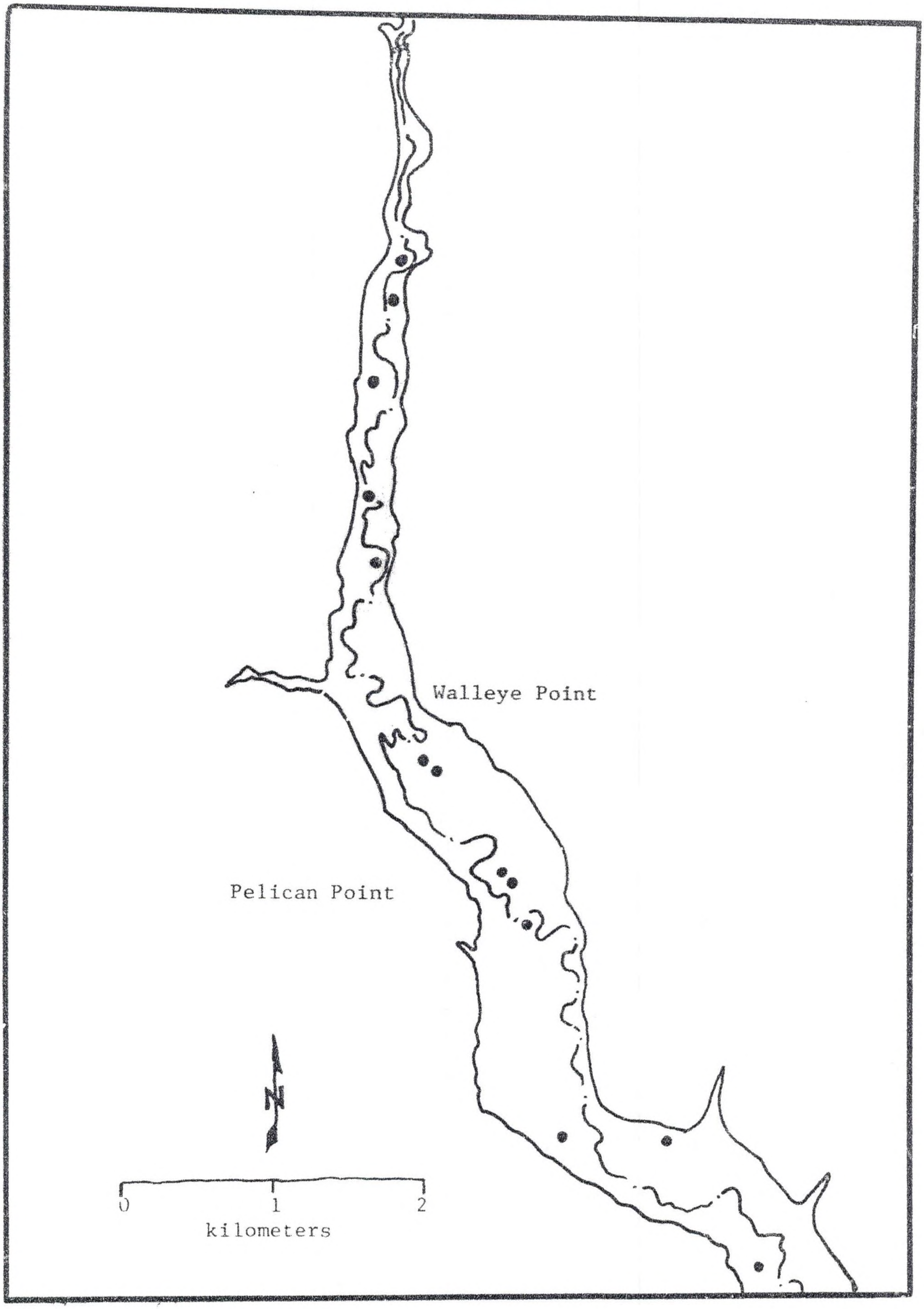
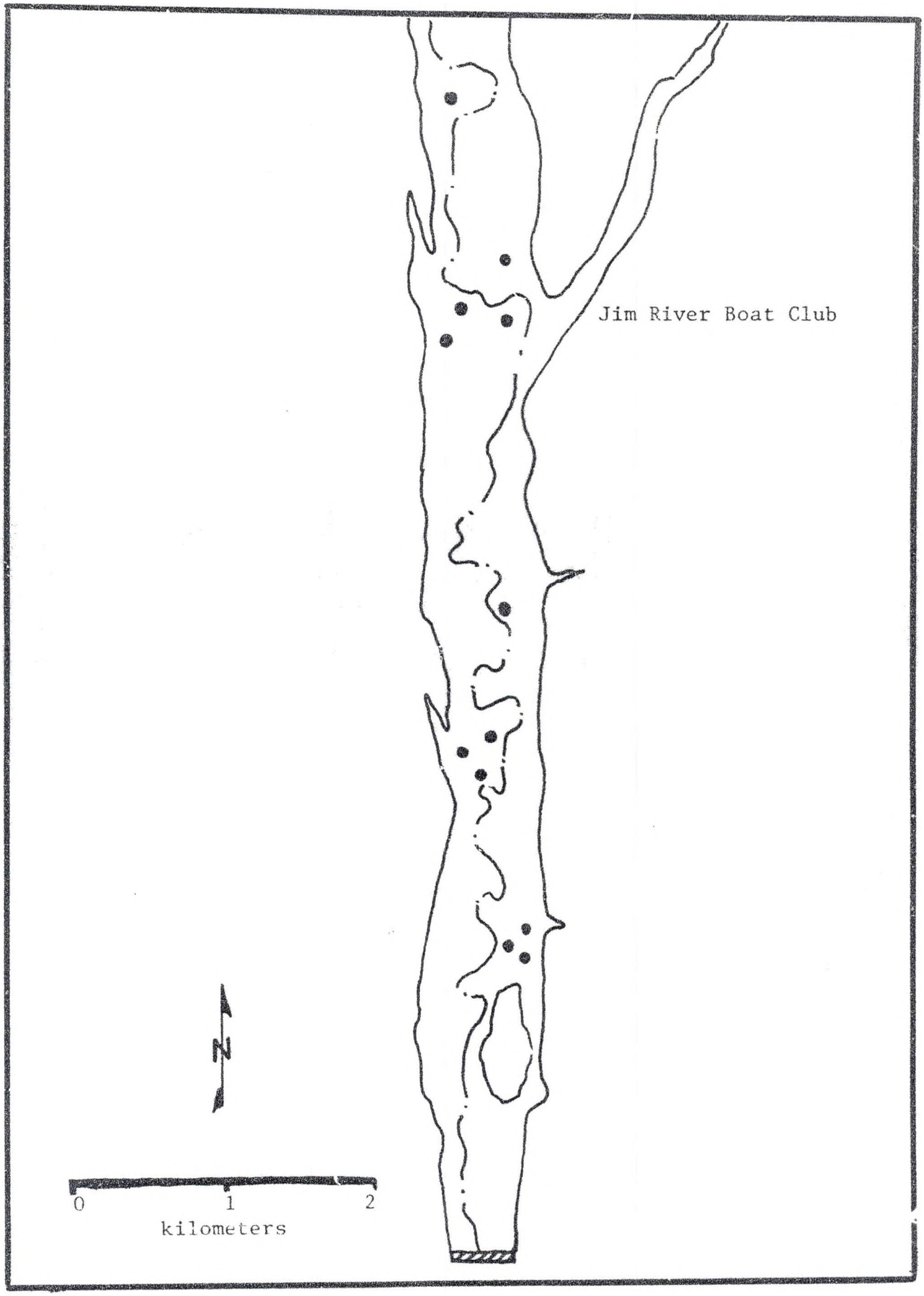

Walleye Point
Pelican Point
N
0
1
2
kilometers

Fig. 14. Locations of walleye 1221 during August 1981


Jim River Boat Club
N
0
1
2
kilometers

By 11 June, it had established an activity area of 56.4 ha near Pelican Point (Fig. 15). On 15 July it was found moving southward from its first activity area. It occupied a second activity area of 37.1 ha approximately 1.8 km south of its former activity area. During this time it ranged as far south as Bullhead Bay (Fig. 16). It returned to its former activity area in early August where it remained until the end of the tracking study.

Fish 1500

Walleye 1500 was captured 21 May north of Pelican Point. The transmitter was implanted at Smokey's Landing and the fish was released at that site. The fish was first located on 1 June. Movements in early June were in the northern part of the reservoir (Fig. 17). During late June and early July, the fish utilized an activity area of 27.7 ha near Pelican Point (Fig. 18). In late July the fish moved to a new activity area of 41.5 ha near Bullhead Bay (Fig. 19). It remained in the Bullhead Bay area until mid-August when it moved back to the Pelican Point area. Average depth occupied by this fish during the study period was 4.8 m.

Movement Patterns

Ultrasonic tagged walleyes when moving could be differentiated from those fish at rest. In general, fluctuating signal strength and changing directions indicated moving walleye. Steady signals from one direction were typical of a resting fish. Resting or motionless fish were seldom observed, the majority of readings indicated some type of movement. Three types of movement patterns were observed during the course of the study; directional, random, and shoreline movements.

Fig. 15. Activity area one of walleye 1450 near Pelican Point

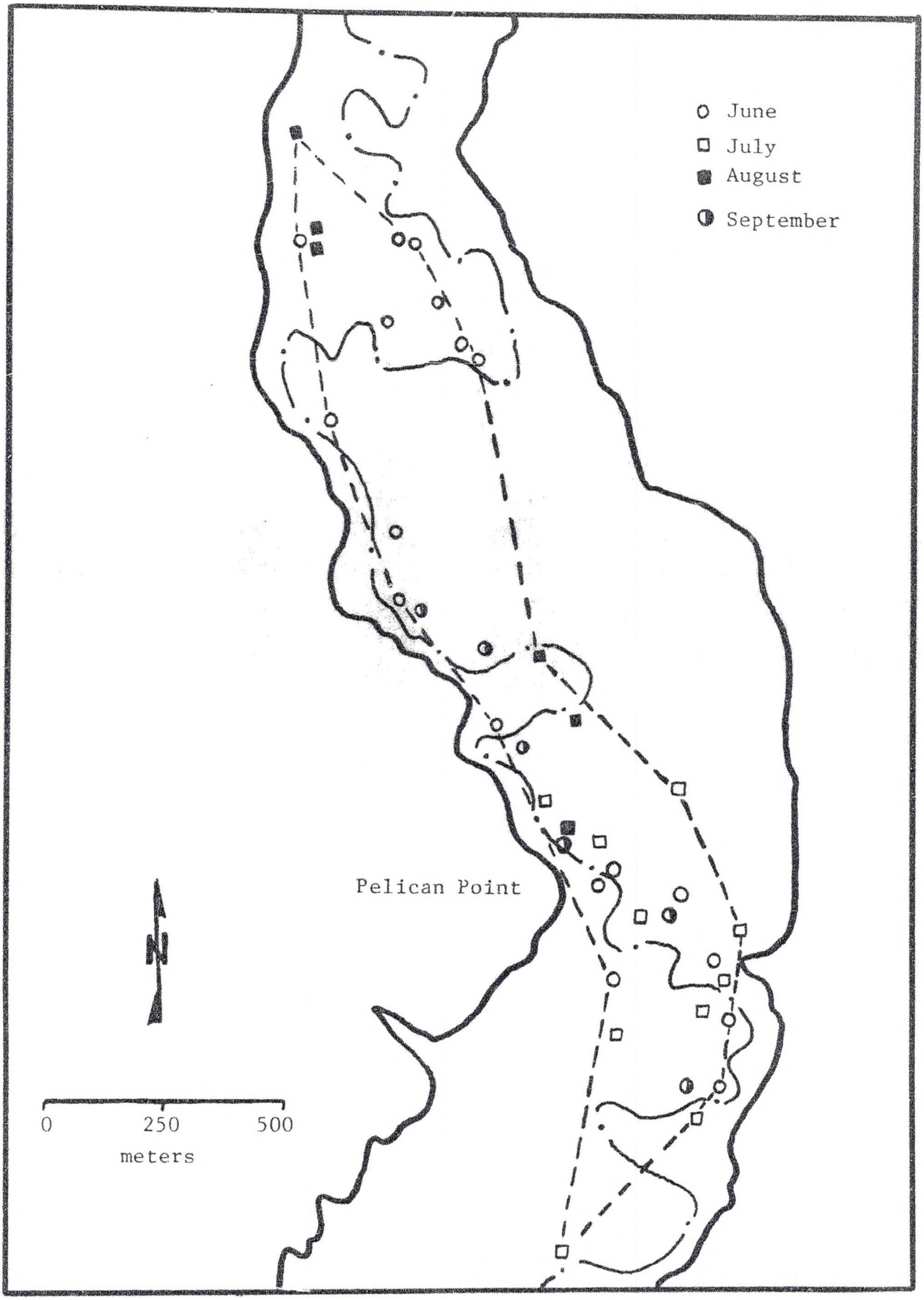

○ June
□ July
■ August
◐ September
Pelican Point
N
0
250
500
meters

Fig. 16. Activity area two of walleye 1450 near Crappie and Bullhead Bays

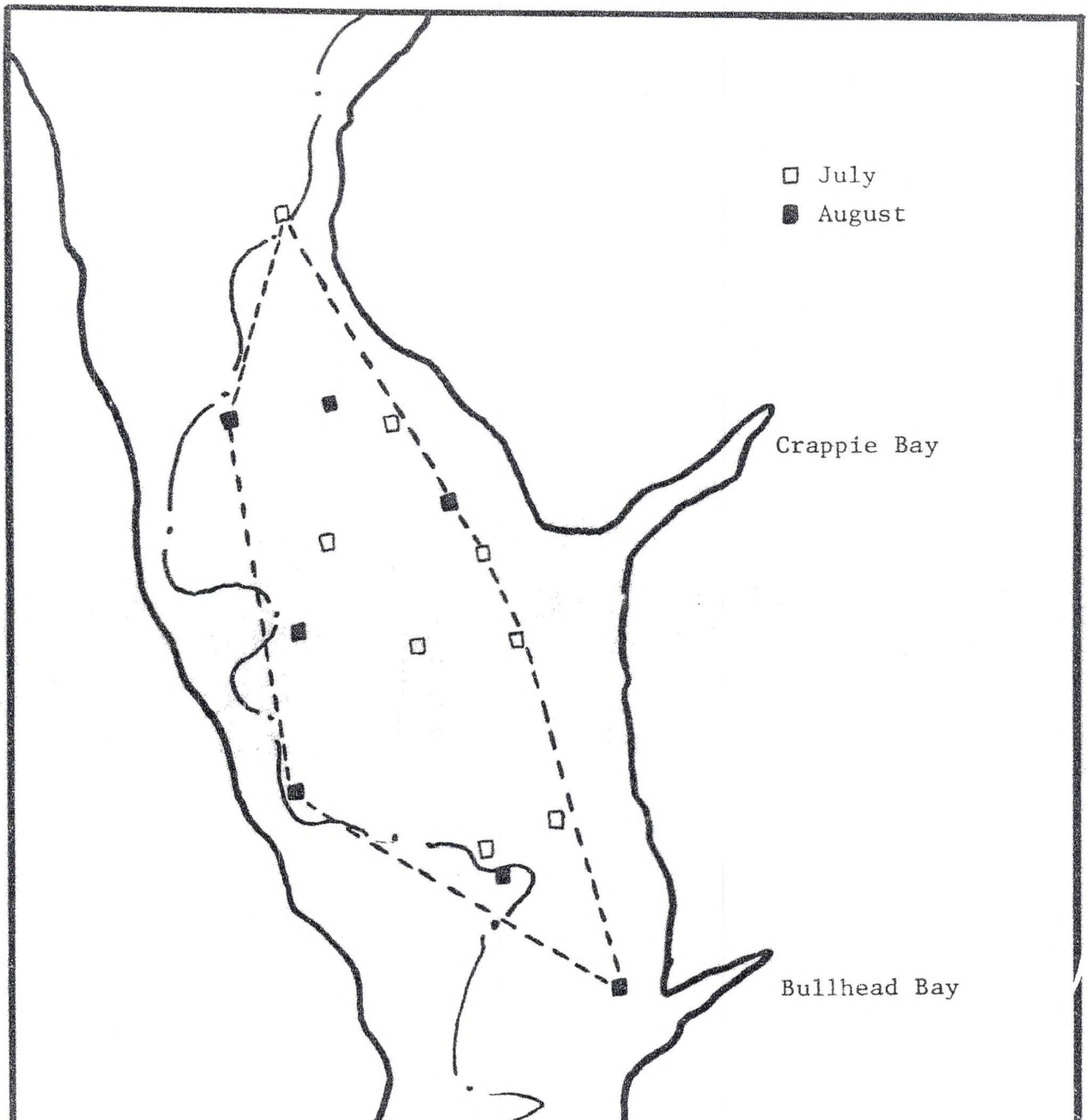

☐ July
■ August
Crappie Bay
Bullhead Bay
N
0
250
500
meters

Fig. 17. Locations of walleye 1500 during June and August 1981

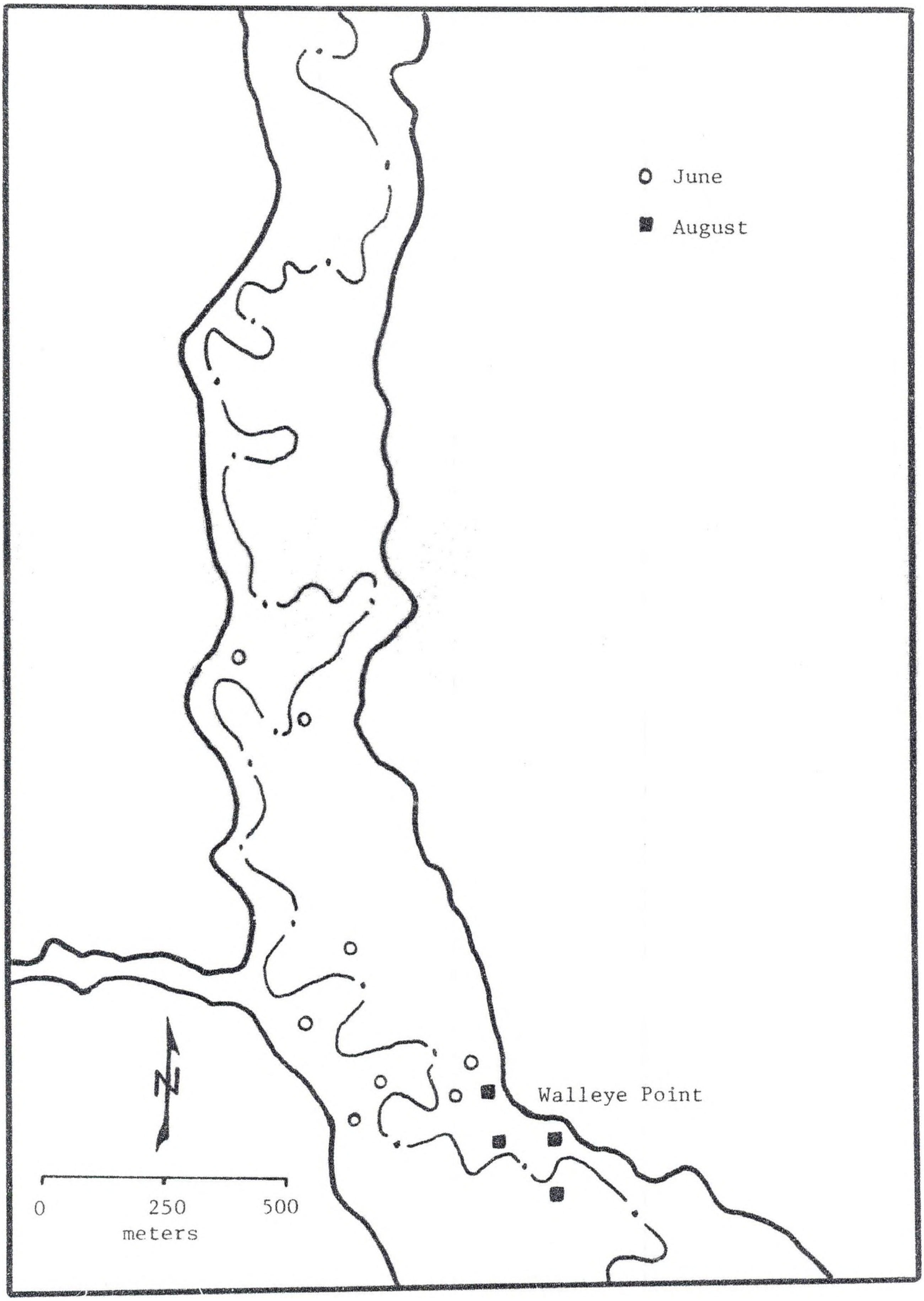

○ June
■ August
Walleye Point
N
0
250
500
meters

Fig. 18. Activity area of walleye 1500 during June and July 1981

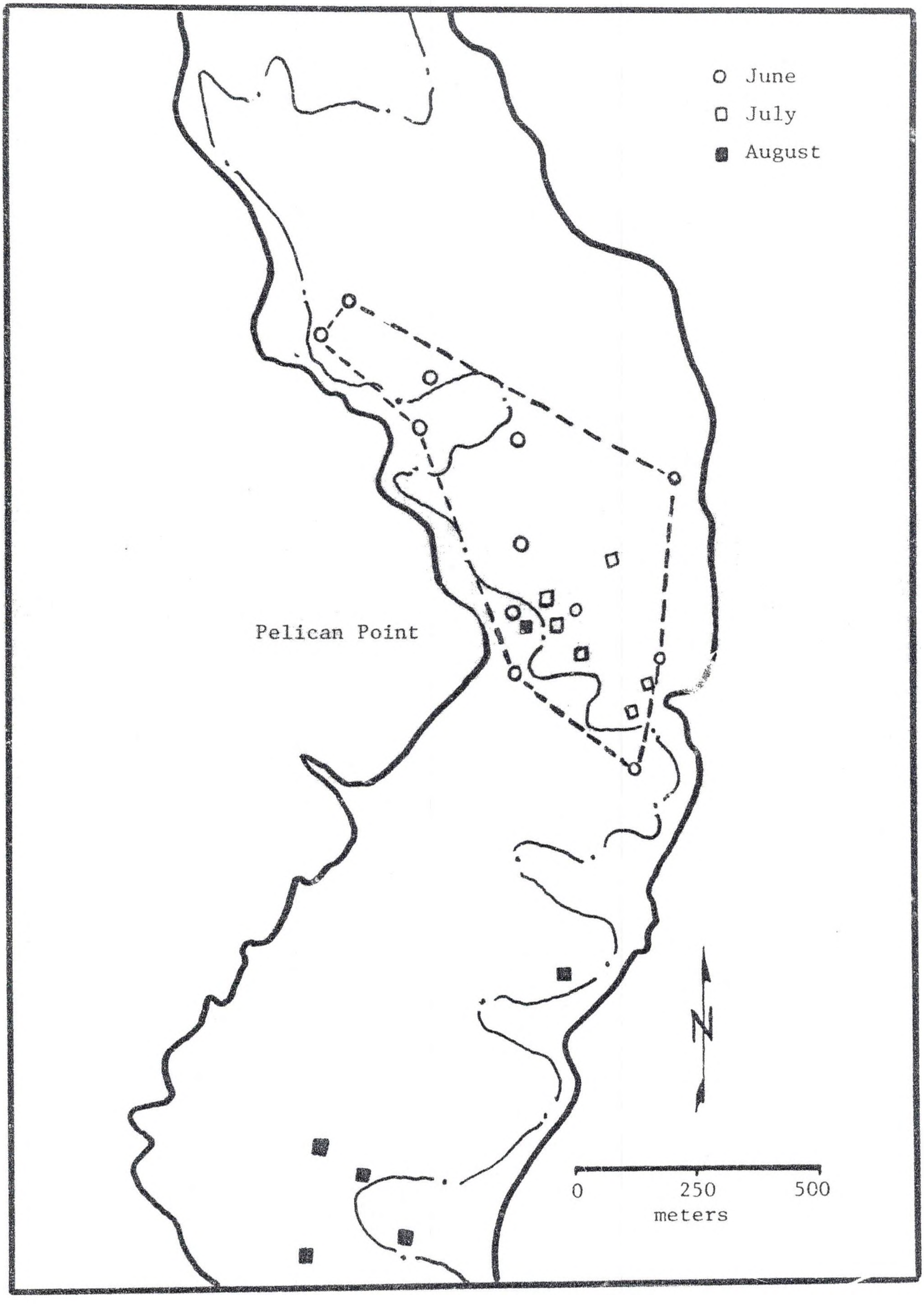
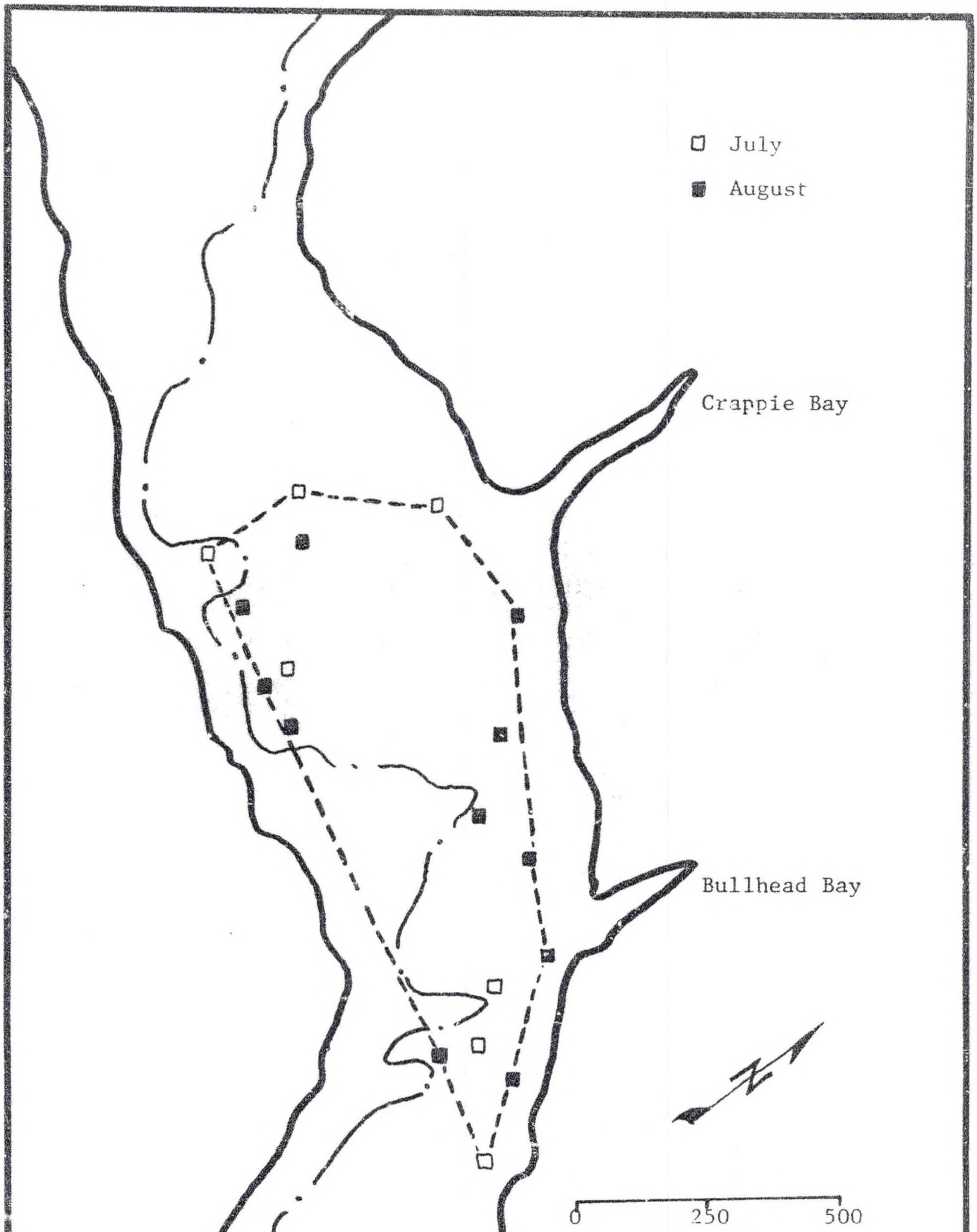

○ June
□ July
■ August
Pelican Point
N
0
250
500
meters

Fig. 19. Activity area of walleye 1500 during late July and early August 1981

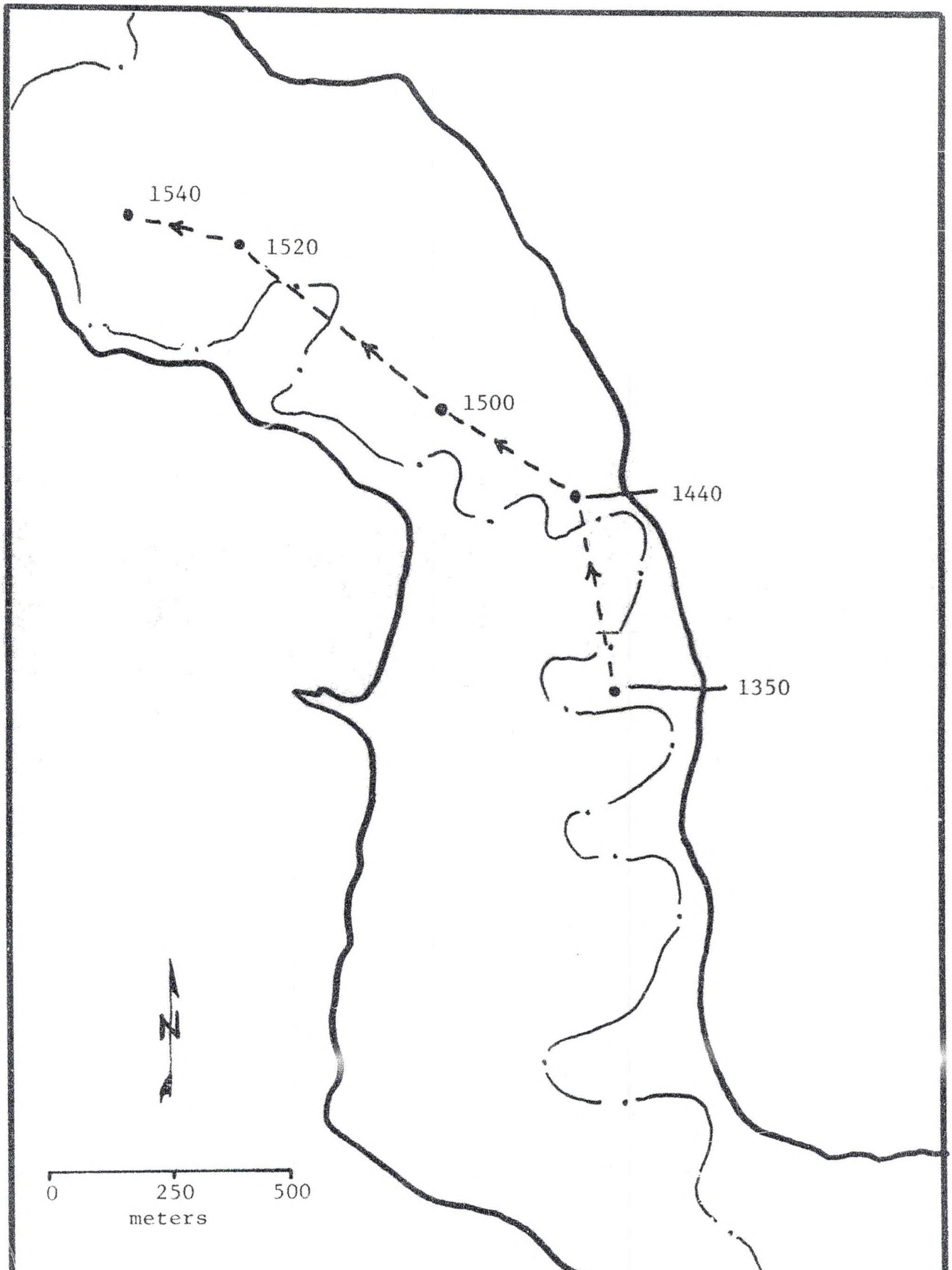

☐ July
■ August
Crappie Bay
Bullhead Bay
N
0
250
500
meters

Directional movement was characterized by swimming in relatively straight lines at rates averaging 400 m/hr. This type of movement was generally observed in fish moving distances greater than 100 m. Directional movements were most often made when fish were moving between feeding and resting areas. These movements were most often seen early in the summer. The frequency of this type of movement diminished as the summer progressed. Directional movement accounted for 89% of the time the fish spent swimming. The movements of fish 1450 during the afternoon of 1 September illustrates this type of movement. As seen in Figure 20, the walleye was initially located near the former river channel southeast of Pelican Point at 1350 hrs. In a little under two hours the fish moved approximately 1590 m from its initial position. Average rate of movement was calculated at 867 m/hr.

The second type of movement was random or "zig-zag" movement. Random movement was determined by rapid changes in direction or by sudden bursts of swimming speed. This type of movement was thought to occur during feeding periods. Random movement patterns occurred during both daylight and night time hours. This type of movement usually occurred well away from the shoreline, generally at distances of at least 20 m.

The third movement pattern consisted of the fish following the shoreline in water approximately 1.5 to 2.0 m deep. Occasional darting movements were often made toward shallow or deep water. This darting movement was thought to be an indication of the walleye chasing forage fish. These movements were usually observed a few hours after sunset or shortly before sunrise. This type of activity was also associated with feeding. The movements of walleye 523 the evening of 26 May is an

Fig. 20. Example of directional movement made by walleye 1450 on 1 September 1981. The time of fish location is expressed in military time.


1540
1520
1500
1440
1350
N
0
250
500
meters

example of this type of movement. The walleye was slowly moving along the shoreline off Smokey's Landing in approximately 1.5 m of water. It would make rapid movements towards shore periodically and would sometimes back-track for a distance before continuing its original course. The shoreline in this area is composed of sand and rocks. Spawning spottail shiners were netted in the vicinity during this time.

Group Associations

During the early part of June, tagged walleyes were found together on several occasions. Grouping of walleyes accounted for less than one percent of the tracking observations during the study. Walleyes were considered to be in group association if two or more fish were found within 10 m of one another.

On 1 June, four of the tagged fish (nos. 523, 845, 1080, 1450) were grouped together approximately 1.5 km south of Buchanan Bridge. Random movements were being made at depths of 1.0 to 2.0 m. It was assumed that the fish were feeding during this period. The following day, 2 June, these fish were again found associated in the same area. Movements were random in water of the same depth as the day before. The same assumption of feeding was made. On both days, the grouping took place between 1130 and 1430 with similar weather conditions, calm and partly cloudy. Dispersal from the area was random and it was concluded that movement away from the area was independent. On 11 June, another grouping of the fish occurred. Six walleyes (nos. 523, 845, 1080, 1221, 1450, and 1500) were associated together off Pelican Point in 6.0 - 7.0 m of water. Movements pattern were random and the walleyes moved in and out of the former river channel. Graph recordings indicated the presence of a number of smaller fish suspended near the river channel. The walleyes seemed to be feeding on these smaller fish. Coordinated movements were not observed and the walleyes were acting independent of one another. During July and August, no other grouped associations of walleyes were observed.

Reaction to External Noise and Net Advoidance

Walleyes in water less than 2.0 m were often observed to be frightened by external noises, such as outboard boat motors or objects dropped in the boat. The typical response of the fish was to flee toward deeper water, usually to the river channel. The fish would usually return within a few minutes if all was quiet. In deeper water, no response to noise was observed. On numerous occasions anglers were observed to troll over tagged walleye in deeper waters without apparent effect.

On several occasions a fright response in tagged walleyes was produced by turning on the graph recorder. This occurred in shallow water (1.0 to 2.0 m). The response was similar to that produced by an external noise but less intense. The walleye would not swim as rapidly or move as far. The response seemed to be more of a reaction to move away from an irritant rather then a genuine fright response. This response to graph recorders was not observed when the fish were in water deeper than 2 m.

An example of what was thought to be net advoidance was obtained 4 August, 1981. Two gill nets were set by the State Game and Fish Department in mid-reservoir between Smokey's Landing and Crappie Bay. At 1200 hours, fish 1450 was near one of the nets. It approached the first net quite closely. It then followed the length of the net before turning and moving in the direction of the second net. Again it moved almost to the second net before turning away. The walleye may have been attracted to the nets by the struggles of other fish already caught in the net.

Habitat Usage

The former river channel was the main habitat or structural feature commonly used by the walleyes during the study. The walleyes were located in or within 20 m of the river channel 70% of the time they were under observation. The channel was used as a route for movements, feeding, and resting.

Feeding areas of the walleyes were generally mud flats bisected by the river channel in water from 1 to 6 m deep. Feeding areas were usually in mid reservoir. No deep water feeding areas were found. Except for the feeding area in the northern end of the reservoir used during early June, submergent vegetation was not present in feeding areas.

The mouths of the small bays were sometimes used by the tagged walleyes. However, the fish seldom ventured into the bay itself. Only Bullhead and Crappie Bays were utilized, the other bays were ignored by the walleye.

There was no indication that walleyes used other habitat features such as submerged brush piles. On several occasions walleyes were found in proximity to artificial tire reefs placed in the reservoir during the summer of 1980. However, the fish did not remain in the area of these reefs for more than a day. These reefs were not located within any activity area and were only encountered during exploratory excursions.

Depth Distribution

Depth preferences varied among individuals throughout the summer. In general, the nomadic fish moved into deeper water than did those fish that established activity areas. A trend toward deeper water was exhibited by all walleyes as the summer progressed (Table 3). Average locational depths for all fish were between four and five meters. These depths accounted for approximately 50% of the fish locations. Figure 21 shows the percentage of occurrence at different depths during the summer. To measure the response of the fish to light intensity, I plotted time of day against depth, assuming that light levels would peak at mid-day. Only data collected on clear, relatively calm days were used to prevent including additional variance. Correlation analysis indicated no significant difference at the 0.05 confidence level (Fig. 22). This indicates that walleyes are not selecting deep water in response to light conditions.

There was no discernable mode of activity. Typically, little daily variation occurred in depth distribution of the walleyes (Fig. 23). No inshore-offshore movements of walleyes were found.

Activity Areas

Five walleyes established activity areas during the course of the study period. Two fish (nos. 845 and 1080) established permanent activity areas in the region near Pelican Point. Two walleyes (nos. 1450 and 1500) had more than one activity area during the summer, shifting

Table 3. Average monthly depth for ultrasonic tagged walleyes in 1981.

Fish ID	May	June	July	August	September
523	3.5[a]	4.1 ± 0.7	4.7 ± 0.9	6.0 ± 1.5	-
695	4.0 ± 0.4	3.4 ± 1.2	2.9 ± 1.1	7.4 ± 2.2	-
845	2.4[a]	4.5 ± 2.3	4.2 ± 0.8	4.6 ± 2.2	3.3 ± 0.8
1080	-	5.8 ± 0.4	4.8 ± 0.8	3.5 ± 0.6	-
1221	-	3.9 ± 1.5	5.9 ± 1.1	8.4 ± 1.0	-
1450	-	4.3 ± 1.6	5.1 ± 1.3	4.5 ± 0.9	4.4 ± 1.5
1500	-	3.4 ± 1.2	2.9 ± 1.1	7.4 ± 2.3	-
Totals	3.5 ± 0.7	4.0 ± 1.4	4.7 ± 1.1	6.1 ± 2.1	3.8 ± 1.1

[a] Standard deviation not computed.

back and forth between areas. Walleye 523 established an activity area near Pelican Point, but abandoned it and became nomadic. The remaining walleyes (nos. 695 and 1221) were nomadic, ranging gradually down reservoir into deeper water as summer progressed.

Activity areas ranged in size from 17.6 to 74.5 ha and averaged 46.4 ha. There appears to be a slight relationship between fish size and the formation of an activity area. Typically, the larger the fish, the less likely it would maintain an activity area. There was little relationship between the size of the activity area and the size of the fish. The sample size of fish did not permit the comparison of activity area to sex, but the only male walleye (1080) had the largest activity area (74.5 ha).

Fig. 21. Percentage of occurrence at various depths

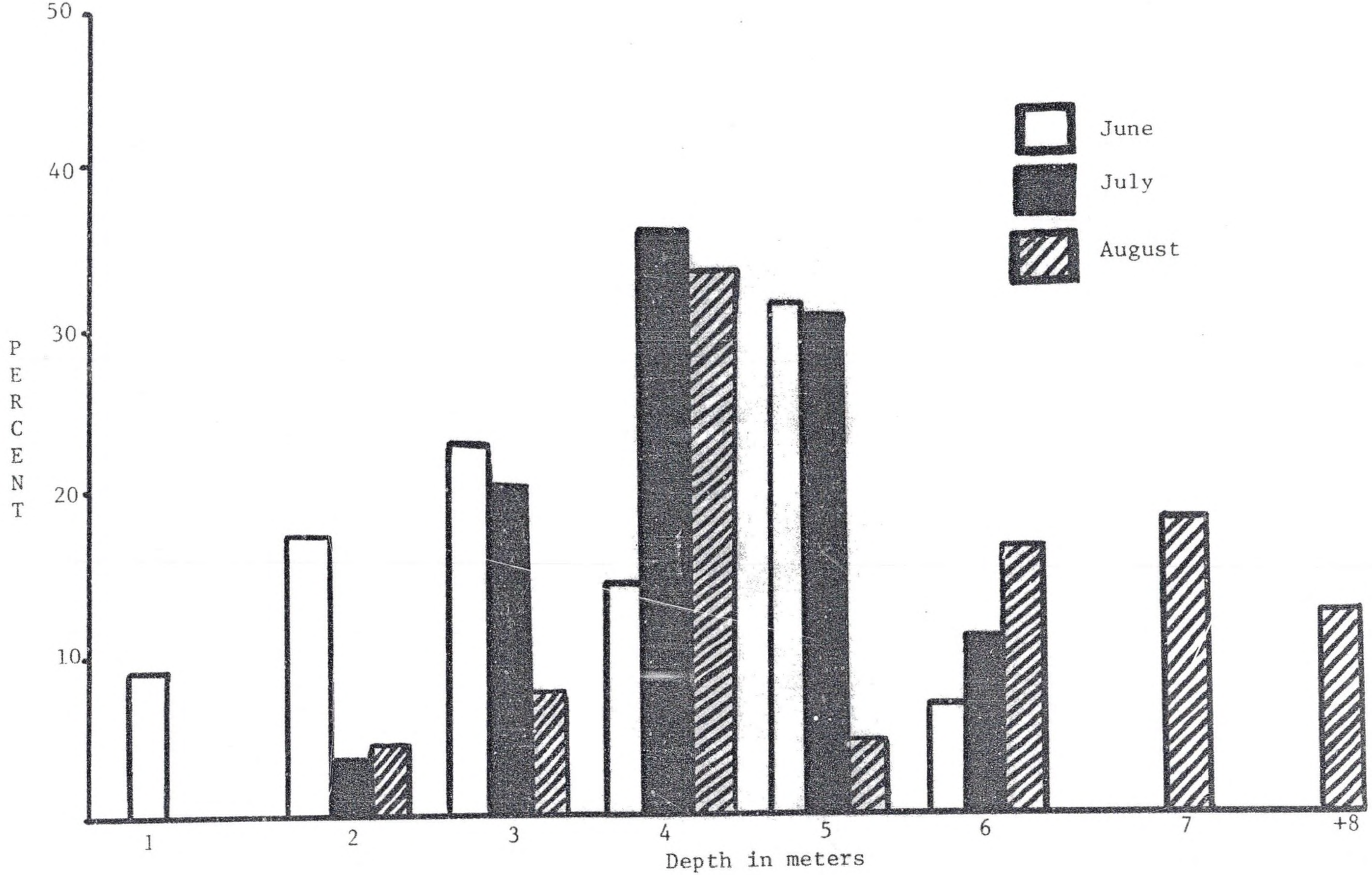

50
40
30
20
10
PERCENT
□ June
■ July
▨ August
1
2
3
4
5
6
7
+8
Depth in meters

Fig. 22. Relationship of depth to time (light)

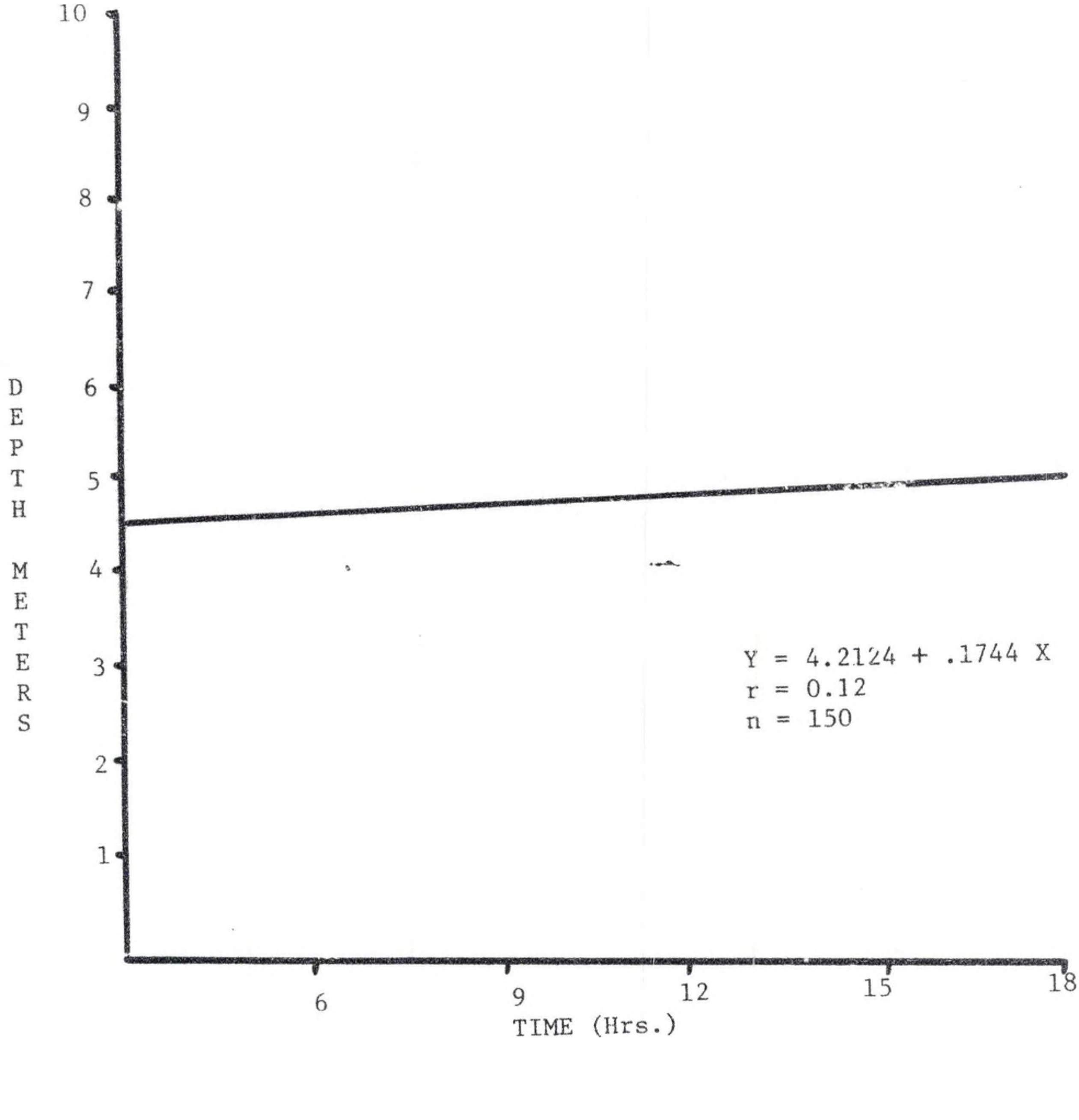
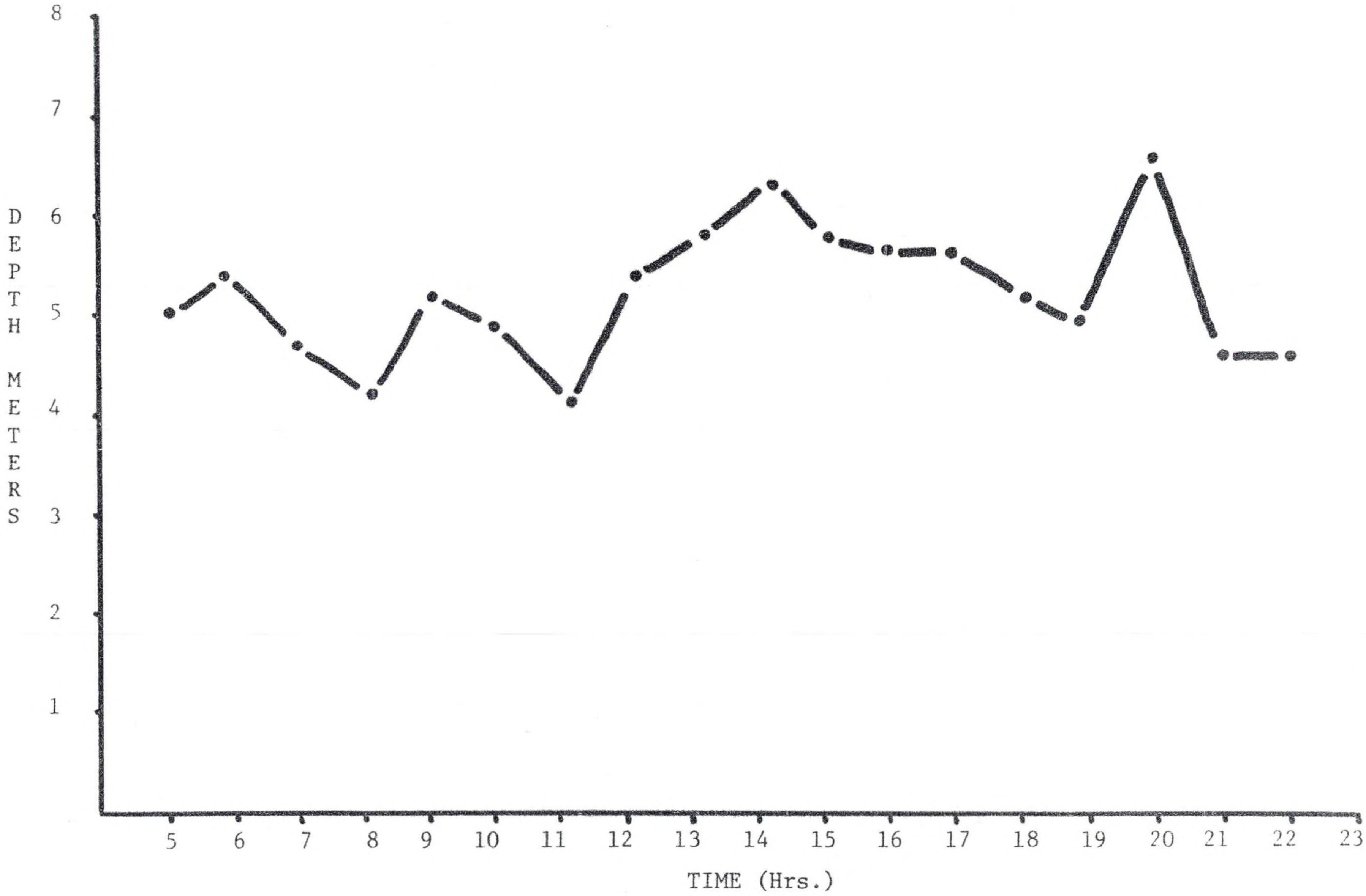

10
9
8
7
6
5
4
3
2
1
DEPTH METERS
Y = 4.2124 + .1744 X
r = 0.12
n = 150
6
9
12
15
18
TIME (Hrs.)

Fig. 23. Average daily depth distribution


DEPTH METERS
8
7
6
5
4
3
2
1
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
TIME (Hrs.)

The activity areas overlapped, particularly in the Pelican Point area. There was little indication of interaction between fish in these overlapping areas. Typically, the walleyes moved independently from each other and were usually located in different sections, well away from each other.

A common feature of all activity areas was the river channel which crossed from one side of the reservoir to the other. Most locational plots of fish within activity areas were concentrated near the channel. Graph recordings made in these areas usually showed schools of small fish.

Relationship with Environmental Factors

Examination of wind velocity, air temperature, barometric pressure, sky and wave conditions failed to produce any trend suggesting influence on walleye activity. A slight trend was found relating swimming direction with wind direction. It was often observed that walleyes tended to swim in the direction with the wind. I also examined the possible influence of the lunar cycle on fish activity. However, no relationship was found to indicate lunar influence on walleye activity.

Water temperature influenced walleye location only in a general way. Because there was little variation in water temperature from top to bottom, walleyes could not select areas based on temperature. However, the fish did leave the northern shallow part of the reservoir when water temperatures approached 21°C.

DISCUSSION

Telemetric Systems Evaluation

The radio transmitters used in 1980 did not perform as expected. Even though it had been thought the conductivity of the water was within acceptable limits, a signal could not be received once the transmitter was in water deeper than 4.5 m. The depth restriction limits the usefulness of radio transmitters for tracking walleyes in Jamestown Reservoir and probably other large bodies of water within North Dakota. At depths less than 4.5 m signals were received. Average range while using the yagi antenna was 300 m, and while using the hand held antenna the average reception range was 100 m.

Ultrasonic biotelemetry used during 1981 worked fairly well, although there were some problems, particularly during windy weather. Underwater noise from waves and boat motors hampered searching activities. Reception ranges averaged 300-400 m, but occasionally the range exceeded 1250 m. These extreme ranges usually occurred during the evening, early in the summer.

Evaluation of Surgical Implantation

Surgical implantation of transmitters proved to be a reliable method for attaching biotelemetric transmitters to walleye. Used with care, the method does not increase the risk of mortality. However, experiences indicated that surgery should not be attempted after the water has warmed above 20°C or after the middle of June. However, females filled with eggs should not be used because the egg sac membrane would be ruptured. It is better to use walleyes captured in trap nets rather than in entanglement nets, as there is a probability of injury in a gill net. If walleyes captured in gill nets must be used, then it is probably better to retain them for 24 hours for observation before release.

The anesthetic mixture of MS-222 and Quinaldine worked very well. Although MS-222 has been used as an anesthetic by itself in numerous studies, it has several disadvantages which I feel makes it unsuitable for fish surgery. MS-222 is fast acting and quickly metabolized. The fish may recover during surgery with disastrous results. On the other hand, prolonged immersion in MS-222 may result in death or damage to the central nervous system. The depth or duration of anesthesia cannot be reliably controlled. Quinaldine has also been used by itself for fish surgery. It is a good fish anesthetic, but it is slow acting and is not water soluble. By mixing the two an anesthetic, which works fast like MS-222 but without its adverse side effects, is obtained.

Activity Areas

The establishment of discrete activity areas by walleyes has been reported in other telemetric studies. Ager (1976) working in Center Hill Reservoir, Tennessee, found that among 18 walleyes tracked for 10 consecutive days, nine established home ranges (activity areas). He defined home range (activity area) as an area repeatedly traversed by a fish during a monitoring period. The size of home ranges during the winter (29.5 to 75.6 ha) was twice as large as those established during the summer (11.8 to 33.7 ha).

Pitlo (1978) reported that walleyes in West Lake Okoboji, Iowa established activity areas from mid-June to mid-October. Activity area size of these fish ranged from 7 to 77 ha. He also found that one walleye used two discrete areas of the lake. An important habitat feature used by the walleyes in this lake was the submergent vegetation, which according to Pitlo allowed the fish to remain in shallow water during the day.

A more complex situation was reported by Einhouse (1981) in Chautauqua Lake, New York. He found that most walleyes (55%) utilized a single activity area, whereas others (18%) used multiple activity areas. The remaining fish (27%) had less defined activity areas and were termed nomadic because their locations were not concentrated in any specific area.

River walleye populations present a different situation. Both Fossum (1975) and Bahr (1977) reported that walleyes in the Mississippi River pools were nomadic, making random movements and not forming activity areas.

The behavior of walleyes in Jamestown Reservoir is a combination of both lake and riverine types. The formation of activity areas is suggestive of lake walleye behavior, but the nomadic behavior is similar to river walleye behavior. A combination of both behavioral types seems logical, because a reservoir may act as either a lake or a river, depending on the time of year.

Familiarity with a specific area within a body of water may aid the walleye in pursuit of prey. Additionally, this familiarity may also allow the fish to quickly escape from danger. The formation of specific activity areas raises interesting problems. Some walleyes in this study did form activity areas while others did not. The nomadic walleyes which did not establish a specific activity area were all large fish. This has also been reported by Einhouse (1981). The reason for this relationship is unclear and further study is needed to resolve this question.

Movement Patterns

Directional movement patterns found in the Jamestown walleye were also observed by Pitlo (1978) in West Lake Okoboji, Iowa. Directional movements occur when feeding areas are separated from resting areas.

Walleye demonstrated the ability to establish its location and home directly to the area where it was captured on several occasions during 1981. These fish were displaced approximately 4 km from the point of capture. All fish returned to the general area of capture within 48 hours. In one case, fish 1221 returned to its capture site within three hours after being released. Various theories concerning orientation have been proposed. Mechanisms such as sun position, magnetic fields, bottom features, and depth have been suggested as possible methods of underwater orientation. I feel a combination of the above methods is used. Certainly bottom features are used because the walleye followed shorelines in all cases when returning to the capture points. But the mechanism used by the fish to establish the correct compass direction could not be determined.

Random or zig-zag movements have been associated with feeding or searching for food. Fossum (1975) visually observed transmittered walleye chasing minnows during such behavior. This type of behavior has also been reported by Pitlo (1978). There is no reason to associate any other type activity with this movement pattern.

Walleyes using the shoreline at night agrees with the findings of Holt et al. (1976). They reported that walleye in Lake Bemidji, Minnesota followed specific bottom contours around the shores of the lake. The Jamestown Reservoir walleye used specific bottom contours in much the same fashion. However the frequency in which Jamestown Reservoir walleye followed bottom contours was much less than in Lake Bemidji. It appears that Jamestown Reservoir walleye utilize the shorelines for feeding when forage fish are concentrated near the shore. Because this type of behavior was witnessed only during dark periods, walleyes may avoid very shallow water during the day because of light or need for security.

The degree of movement or lack of movement may be an indicator of prey availability within a given body of water. If one considers a bioenergetic approach (that is a predator will expend the least amount of energy in pursuit of its prey), then intuitively movement should be less with high prey densities and greater with low prey densities. This is supported somewhat in Jamestown Reservoir. Test nettings running concurrently with the biotelemetry suggest relatively low desities of prey (Steinwand 1982). The majority of the monitored walleye wandered extensively throughout the summer, either in large activity areas or over the entire reservoir. This is suggestive of a constant need to search for food. Although angler reports are somewhat misleading, most anglers report difficulty in locating walleyes during the summer. If walleyes are forced to spend considerable time moving around in search of food and are thus less concentrated this could result in lower angler catches.

Examination of other possible influences on daily movement failed to produce any significant correlation. Many anglers hold the viewpoint that fish behavior is affected by such conditions as changes in barometric pressure and "lunar phases." Observations in Jamestown Reservoir do not support such beliefs.

Seasonal Movements

The capture sites of the walleye suggest that the northern section of the reservoir is used more in the spring than in the summer. Movement into this area is probably in response to increased flows at this time. Walleyes probably remain in the upper part of the reservoir after attempting to spawn as a result of forage concentrations. In mid-June the shallow, northern section of the reservoir is abandoned. Three possible reasons for abandonment of the upper area include; increasing water temperatures, increased growth of aquatic vegetation, or decreased availability of prey. Water temperature is probably the main cause of the walleyes leaving the north section of the reservoir. The increased growth of sago pondweed may make it difficult for the larger walleyes to hunt small fish in the turbid waters of the reservoir.

Depth Distribution

Average depths used during the summer by Jamestown Reservoir walleyes agrees with findings reported by others. Pitlo (1978) found that walleyes in Lake Okoboji, Iowa were usually in shallow waters (2-6 m), with the 4-5 m range accounting for 92 percent of the readings.

He reported that walleyes in this lake used aquatic vegetation to reduce light intensity during the day rather than seek deeper waters. Holt et al. (1976) reported that walleyes preferred depths above 5.0 m in Lake Bemidji, Minnesota. In Chautauqua Lake, New York, Einhouse (1981) found that walleyes which established activity areas were located most frequently in 2.0 to 4.0 m and that nomadic walleyes were often found suspended over deep water. Kelso (1976) found that walleye occupied the 2.0 to 5.0 m depths.

Selection of certain depths by walleyes has been thought to be a response to ambient light conditions (Ryder 1977). Most studies dealing with depth preference have dealt with walleye populations in mesotrophic environments. However, abundant walleye populations are also found in eutrophic waters with soft substrates. The high turbidities found in such waters reduces light penetration, allowing the walleye to remain shallower than its mesotrophic counterpart all other factors being equal. In mesotrophic waters, walleyes have shifted to deeper water seeking shelter under vegetation and boulders, or they have moved to turbid areas to compensate for light conditions (Ryder 1977). This shift to deeper water was not observed in Jamestown Reservoir.

Conclusions

I believe that the walleye is a very adaptable and successful species, which can adjust its behavior to a variety of the local environments. Too often the literature tends to stereotype walleye behavior. Many studies conducted in mesotrophic waters have unintentionally given rise to this stereotype. Unfortunately, the popular fishing press has picked up on these stereotyped findings and has increased the spread of the stereotype concept. I feel that the resident walleye population in each body of water is unique, broadly adapting its behavior to local conditions. While I grant that there are general behavioral tendencies, the ecological differences between bodies of water may produce somewhat different behavioral patterns in each local population which may have important management consequences. In lakes or reservoirs where walleyes concentrate in specific areas, angling pressure may take a higher toll than in waters in which the walleyes are more nomadic. Also the effect of walleye movement and behavior during sampling may influence population estimates.

I see a need for more and better telemetric studies over a wide range of walleye waters to provide a more complete understanding of this species. More elaborate experiments need to be performed to test the various influences of the environment on walleye behavior. Biotelemetric studies should also run concurrently with other types of studies to correlate data impossible to obtain with telemetry. While current biotelemetry is fairly costly, the long-term benefits of such studies may reduce the costs of fish management by increasing the effectiveness of walleye management programs. I feel that the telemetric studies to date have only just begun to scratch the surface of the complex behavior of walleye and its relationship to the environment.

LITERATURE CITED

Aadland, L.T. 1982. Artificial reef as a fishery management tool to improve sport fishing in North Dakota reservoirs. M.S. Thesis, North Dakota State University, Fargo, North Dakota. (in preparation)

Ager, L.M. 1976. A biotelemetry study of the movements of the walleye in Center Hill Reservoir, Tennessee. M.S. Thesis, Tenn. Tech. Univ., Cookeville, Tenn. 97 pp.

Bahr, D.M. 1977. Homing, swimming behavior, range activity patterns and reaction to increasing water levels of walleye (*Sizostedion vitreum vitreum*) as determined by radio-telemetry in navigational pools 7 and 8 of the upper Mississippi River during spring 1976. M.S. Thesis, Univ. of Wis., LaCrosse, Wis. 67 pp.

Bailey, R.M., J.E. Fitch, E.S. Herald, E.A. Lachner, C.C. Lindsey, C.R. Robins, and W.B. Scott. 1970. A list of common and scientific names of fishes from the United States and Canada. Spec. Publ. Amer. Fish. Soc. 6:150 pp.

Berard, E.E. 1978. Investigations on the influence of smelt on the walleye in Lake Sakakawea, North Dakota. N.D. Game and Fish Dept. Dingell-Johnson Project F-2-R-25. Report No. 1058.

Bidgood, B.F. 1980. Field surgical procedure for implantation of radio tags in fish. Alberta Fish and Wildlife Div. Fish. Res. Rep. No. 20. 9 pp.

Brumbaugh, D. 1981. Personal Communication, Sonotronics Inc. Tucson, Az.

Brumbaugh, D. 1980. Effects of thermal stratification on range of ultrasonic tags. Underwater telemetry Newsletter. 10:1-4.

Bulkley, R.V., V.L. Spykermann, and L.E. Inmon. 1976. Food of the pelagic young of walleyes and five cohabiting fish species in Clear Lake, Iowa. Trans. Amer. Fish. Soc. 105:77-83.

Burt, W.H. 1943. Territoriality and home range concepts as applied to mammals. J. Mammal. 24:345-352.

Camp, L. 1970. Underwater acoustics. John Wiley and Sons Inc., New York. 308 pp.

Carlander, K.D. and R.E. Cleary. 1949. The daily activity patterns of some freshwater fishes. Amer. Mid. Nat. 41:447-452.

Cassity, R.L. 1979. A comparison of age and growth of walleyes, Stizostedion vitreum vitreum (Mitchill), in Lakes Audubon and Sakakawea, North Dakota, 1978. M.S. Thesis, University of North Dakota.

Chevalier, J.R. 1973. Cannibalism as a factor in first year survival of walleye in Oneida Lake. Trans. Amer. Fish. Soc. 102:739-744.

Colby, P.J., R.E. McNicol, and R.A. Ryder. 1979. Synopsis of biological data on the walleye Stizostedion v. vitreum (Mitchill 1818). FAO Fisheries Synopsis No. 119:139 pp.

Collette, B.B., and P. Banarescu. 1977. Systematics and zoogeography of the fishes of the family Percidae. J. Fish. Res. Board Can. 34:1450-1463.

Crowe, W.E. 1962. Homing behavior in walleyes. Trans. Amer. Fish. Soc. 91:350-354.

Disler, N.N., and S.A. Smirnov. 1977. Sensory organs of the lateral-line canal system in two percids and their importance in behavior. J. Fish. Res. Board Can. 34:1492-1503.

Dobie, J. 1966. Food and feeding habits of the walleye, Stizostedion v. vitreum, and associated game and forage fishes in Lake Vermillion, Minnesota, with special reference to the tullibee, Coregonus (Leucichtys) artedi. Minn. Fish. Invest., 4:33-71.

Dodson, J.J., W.C. Leggett and R.A. Jones. 1972. The behavior of adult American shad (Alosa sapidissima) during migration from salt to fresh water as observed by ultrasonic tracking techniques. J. Fish. Res. Board Can. 29:1445-1449.

Dombeck, M.P. 1979. Movement and behavior of the muskellunge determined by radio-telemetry. Wis. Dept. Nat. Res. Tech. Bull. No. 113. 19 pp.

Duerre, D.C. 1977. Angler questionnaire survey. N.D. Game and Fish Dept. Dingell-Johnson Project F-2-R-22 and 23. Report No. A-1049.

Einhouse, D.W. 1981. Summer-fall movements, habitat utilization, diel activity and feeding behavior of walleyes in Chautauqua Lake, New York. M.S. Thesis, State University College at Fredonia, New York. 107 pp.

Eschmeyer, P.H. 1950. The life history of walleye, Stizostedion vitreum vitreum (Mitchill), in Michigan, Bull. Mich. Dep. Conserv., Inst. Fish. Res. 3:99 pp.

Everhart, W. H., A.W. Eipper, and W.D. Young. 1975. Principles of Fishery science. Cornell University Press, Ithaca, New York. 288 pp.

Ferguson, R.G., and A.J. Derksen. 1971. Migrations of adult and juvenile walleyes (*Stizostedion vitreum vitreum*) in southern Lake Huron, Lake St. Clair, Lake Erie and connecting waters. J. Fish. Res. Board Can. 28:1133-1192.

Fisher, J. 1976. Tuning in on wildlife. National Wildlife. 14(3): 20-23.

Forney, J.L. 1974. Interactions between yellow perch abundance, walleye predation, and survival of alternate prey in Oneida Lake, New York. Trans. Amer. Fish. Soc. 103:15-24.

Fossum, J. D. 1975. Age and growth, food habit analysis and movement patterns of walleye (*Stizostedion vitreum vitreum* (Mitchill)) in pools 3 and 4 of the upper Mississippi River. M.S. Thesis, St. Mary's College, Winona, Minn. 144 pp.

Fried, S.M., J.D. McCleave, and K.A. Stred. 1976. Buoyancy compensation by Atlantic salmon (*Salmo salar*) smolts tagged internally with dummy telemetry transmitters. J. Fish. Res. Board Can. 33:1377-1380.

Fryer, T.B. 1974. Power sources for implanted telemetry systems. Biotelemetry. 1:31-40.

Gardella, E.S. and A.B. Stasko. 1974. A linear-array hydrophone for determining swimming depth of fish fitted with ultrasonic transmitters. Trans. Amer. Fish. Soc. 103:635-637.

Gray, R.H. and J.M. Haynes. 1977. Depth distribution of adult Chinook salmon (*Oncorhynchus tshawytscha*) in relation to season and gas-super saturated water. Trans. Amer. Fish. Soc. 106:617-620.

Hanson, D.A. 1978. Chemical and physical characteristics of the James River from Arrowwood Refuge to the outflow of Jamestown Dam, North Dakota. M.S. Thesis, North Dakota State University, Fargo, North Dakota. 77 pp.

Harlan, J.R., and E.B. Speaker. 1969. Iowa fish and fishing. 4th ed. State of Iowa, Iowa Cons. Comm., Des Moines, Ia. 365 pp.

Hart, L.G. and R.C. Summerfelt. 1975. Surgical procedures for implanting ultrasonic transmitters in flathead catfish (*Pylodictis olivaris*). Trans. Amer. Fish. Soc. 104:56-59.

Hasler, A.D. and W.J. Wisby. 1958. The return in displaced largemouth bass and green sunfish to a "home" area. Ecology 39:289-293.

Hokanson , K.E. 1977. Temperature requirements of some Percids and adaptations to the seasonal temperature cycle. J. Fish. Res. Board Can. 34:1524-1550.

Holt, C.S., G.D.S. Grant, G.P. Oberstar, C.C. Oakes, and D.W. Bradt. 1977. Movement of walleye, *Stizostedion vitreum vitreum*, in Lake Bemidji, Minnesota, as determined by radio-biotelementry. Trans. Amer. Fish. Soc. 106:163-169.

Ireland, L.C. and J.W. Kanwisher. 1978. Underwater acoustic biotelemetry: procedures for obtaining information on the behavior and physiology of free-swimming aquatic animals in their natural environments. Pages 342-379 *in* D.I. Mostofsky, ed. The behavior of fish and other aquatic animals. Academic Press Inc., New York.

Johnson, J.H. 1960. Sonic tracking of adult salmon at Bonneville Dam, 1957. U.S. Fish Wildl. Serv. Fish. Bull. 60(176):471-485.

Johnson, M.G., J.H. Leach, C.K. Minns, and C.H. Olver. 1977. Limmnological characteristics of Ontario lakes in relation to associations of walleye (*Stizostedion vitreum vitreum*), northern pike (*Esox lucius*), lake trout (*Salvelinus namaycush*), and smallmouth bass (*Micropterus dolomieui*). J. Fish. Res. Board Can. 34:1592-1601.

Kazihara, T., S. Shirahata, and M. Sooma. 1972. Radio-tracking of rainbow trout movements in Lake Chuzenji. Fish. Res. Board Can. Transl. Ser. No. 2284. 19 pp.

Keuchle, L. 1980. Personnal Communication, Cedar Creek Bioelectronics Laboratory, Bethal, Mn.

Kelso, J.R.M. 1976. Diel movements of walleye, *Stizostedion vitreum vitreum*, in West Blue Lake, Manitoba, as determined by ultrasonic tracking. J. Fish. Res. Board Can. 33:2970-2972.

Konstantinov. K.G. 1977. Modern methods of fish tagging. Journal of Ichthyology. 17:924-938.

Leggett, W.C. and R.A. Jones. 1971. Net Advoidance behavior in American shad (*Alosa sapidissima*) as observed by ultrasonic tracking techniques. J. Fish. Res. Board Can. 28:1167-1171.

Lonsdale, E.M. 1969. Radio telemetry as a tool in the study of fresh water fish. Annu. Rocky Mountain Bioeng. Symp. Conf. Rec. 6:40-45.

Malinin, L.K. 1970. Use of ultrasonic transmitters for tagging bream and pike. Report I. Reaction of fish to net webbing. Biol. Vnutr. Vod Iform. Byull. 7:64-69. (Translated from Russian by Fish. Res. Board Can. Transl. Ser. 1818. 8 p.)

________. 1972. Home range and actual paths of fish in the river pool of the Rybinsk Reservoir. Biol. Vnutr. Vod Iform. Byull. 22(25): 158-166. (Translated from Russian by Fish. Res. Board Can. Transl. Ser. 2282. 26 pp.)

Malinin, L.K. and A.M. Svirskii. 1973. Application of telemetry to ichthyology. TSNIITEI Rybnogokhozyaystra. Rybokhozyaystvennoe Ispol' Zovanie Resursov Mirovogo Okeana 1(4):17-39. (Translated from Russian by Fish. Res. Board Can. Transl. Ser. 2707. 29 pp.)

McCleave, J.D. and R.M. Horrall. 1970. Ultrasonic tracking of homing cutthroat trout (Salmo clarki) in Yellowstone Lake. J. Fish. Res. Board Can. 27:715-730.

McCleave, J.D., L.A. Jahn, and C.J.D. Brown. 1967. Miniature alligator clips as fish tags. Prog. Fish Cult. 29:60-61.

Mitson, R.B. 1978. A review of biotelemetry techniques using acoustic tags. Pages 253-283 in J.E. Thorpe, ed. Rhythmic activity of fishes. Academic Press Inc., New York.

Monan, G.E. and K.L. Liscom. 1971. Radio tracking of adult spring chinook salmon below Bonneville Dam, 1971. Final Report NOAA, Nat. Marine. Fish. Ser., N. Pac. Fish. Res. Center, Seattle, Wash. 24 pp.

Morris, W.K. 1977. Evaluation of methods of attaching simulated ultrasonic transmitters to adult male walleye, Stizostedion vitreum vitreum (Mitchill), under adverse environmental conditions. M.S. Thesis, Univ. of Okla., Norman, Okla. 116 pp.

Ney, J.J. 1978. A synoptic review of yellow perch and walleye biology. Pages 1-12 in R.L. Kendall, ed. Selected coolwater fishes of North America. Amer. Fish. Soc. Spec. Publ. 11.

Olson, D.E. and W.J. Scidmore. 1962. Homing behavior of spawning walleye. Trans. Amer. Fish. Soc. 91:355-361.

Owen, J.B., D.S. Elsen, and G.W. Russell. 1981. Distribution of fishes in North and South Dakota Basins affected by the Garrison Diverson Unit. Fisheries Research Unit, University of North Dakota. 211 pp.

Pauley, J.D., C. Kaltenback, R.W. Weeks, F.M. Long, and W. Marshall. 1979. EKG electrode implacement and signal filtering for heart rate monitoring. Pages 135-144 in Second International Conference on Wildlife Biotelemtry. University of Wyoming, Laramie, Wyoming.

Pincock, D.E. and D.M. Luke. 1975. Pressure-sensing transmitter, Under water Telemetry Newsletter. 5:10-11.

________. 1979. Ultrasonic Biotelemetry - systems considerations. Pages 248-253 in F.M. Long, ed. Proceedings of the Second International Conference on Wildlife BioTelemetry. University of Wyoming, Laramie, Wyoming.

Pitlo, J.M. Jr. 1978. Walleye movement and behavior in West Lake Okoboji, Iowa. M.S. Thesis, Iowa State Univ., Ames, Iowa. 87 pp.

Poddubny, A.G. 1969. The results of preliminary experiments in tracking sturgeon carrying electronic tracer tags. Voprosy Ikhtiologii 6 (4):725-734. (Translated from Russian by Natl. Lending Libr. Sci. Technol., U.K.)

Priegel, G.R. 1969. Food and growth of young walleyes in Lake Winnebago, Wisconsin. Trans. Amer. Fish. Soc. 98:121-124.

Reigier, H.A., V.C. Applegate, and R.A. Tyder. 1969. The ecology and management of walleye in western Lake Erie. Great Lakes Fish. Comm. Tech. Rep. 15. 101 pp.

Ross, M.J. 1978. Distribution of fish and temperature preference of yellow perch in the thermal plume of a power plant as determined by radio telemetry. M.S. Thesis, Univ. of Minnesota. 127 pp.

________., V.B. Kuechle, R.A. Reichle and D.B. Siniff. 1979. Automatic radio telemetry recording of fish temperatures and depth. Pages 238-247 in Proceedings of the Second International Conference on Wildlife Biotelemetry. University of Wyoming, Laramie, Wyoming.

Ryder, R.A. 1977. Effects of ambient light variations on behavior of yearling, subadult, and adult walleyes (Stizostedion vitreum vitreum). J. Fish. Res. Board Can. 34:1481-1491.

________. 1968. Dynamics and exploitation of mature walleyes, Stizostedion vitreum vitreum, in the Nipigon Bay region of Lake Superior. J. Fish. Res. Board Can. 28:1347-76.

Schiefer, K. and G. Power. 1972. Tracking in a turbulent river. Underwater Telemetry Newsletter. 2:14-15.

Scott, W.B. and E.J. Crossman. 1973. Freshwater fishes of Canada. Fish. Res. Board Can. Bull. 184. 966 pp.

Shepherd, B. 1973. Transmitter attachment and fish behavior. Underwater Telemetry Newsletter. 3:8-11.

Spangler, G.R., N.R. Payne, and G.K. Winterton. 1977. Percids in the Canadian waters of Lake Huron. J. Fish. Res. Board Can. 34:1839-1848.

Stasko, A.B. and D.G. Pincock. 1977. Review of underwater biotelemetry, with emphasis on ultrasonic techniques. J. Fish. Res. Board Can. 34:1261-1285.

________., R.M. Horrall, and A.D. Hasler. 1976. Coastal movements of adult Fraser River sockeye salmon (Oncorhynchus nerka) observed by ultrasonic tracking. Trans. Amer. Fish. Soc. 105:64-71.

________., R.M. Horrall, A.D. Hasler, and D. Stasko. 1973. Costal movements of mature Fraser River pink salmon (Oncorhynchus gorbuscha) as revealed by ultrasonic tracking. J. Fish. Res. Board Can. 30:1309-1316.

Steinwand, T.R. 1982. Some effects of harvesting commercial fishes in Jamestown Reservoir, North Dakota. M.S. Thesis, University of North Dakota. (in preparation)

Summer, G.L. 1980. Canton walleye distribution. Underwater Telemetry Newsletter. 10:13-14.

Swenson, W.A. 1977. Food consumption of walleye (Stizostedion vitreum vitreum) and sauger (S. canadense) in relation to food availability and physical conditions in Lake of the Woods, Minnesota, Shagawa Lake, and western Lake Superior. J. Fish. Res. Board Can. 34:1643-1654.

Tesch, F.W. 1976. Fish tracking by the gradient direction finding technique. Underwater Telemetry Newsletter. 6:11-13.

Trautman, M.B. 1957. The fishes of Ohio. Ohio State University Press. Columbus, Ohio. 683 pp.

Trefethen, P.S. 1956. Sonic equipment for tracking individual fish. U.S. Fish and Wildl. Serv., Spec. Sci. Rep. No. 179. 11 pp.

Urick, R.J. 1973. Principles of underwater sound. 2nd ed. McGraw Hill, Inc., New York. 384 pp.

U.S. Bureau of Reclamation. 1974. Initial stage, Garrison Diverson Unit: Final environmental statement. U.S. Bur. Reclamation Int. Fes. 74-3.

U.S. Environmental Protection Agency. 1976. National eutrophication survey. working paper No. 570 (Jamestown Reservoir). Corvallis, Oregon. (Mimeographed).

Van Eeckhout, G. 1981. Personal Communication, North Dakota State Game and Fish Department, Jamestown, ND.

Velle, J.I., J.E. Lindsay, R.W. Weeks and F.M. Long. 1979. An investigation of the loss mechanisms encountered in propagation from a submerged fish telemetry transmitter. Pages 228-237 in Proceedings of the Second International Conference on Wildlife Biotelemetry. University of Wyoming, Laramie, Wyoming.

Wagner, W.C. 1972. Utilization of alewives by inshore piscivorous fishes in Lake Michigan. Trans. Amer. Fish. Soc. 101:55-63.

Walker, R.E. and R.L. Applegate. 1976. Growth, food, and possible ecological effects of young-of-the-year walleye in a South Dakota prairie pot-hole. Prog. Fish. Cult. 38:217-220.

Winter, J.D. 1976. Movements and behavior of largemouth bass (Micropterus salmoides) and steelhead (Salmo gairdneri) determined by radio telemetry. Ph.D. thesis, Univ. Minnesota. 200 pp.

______., V.B. Kuechle, and D.B. Siniff. 1973. An Underwater radio tracking system. Underwater Telemetry Newsletter. 3:4-5.

________., V.B. Kuechle, D.B. Siniff, and J.R. Tester. 1978. Equipment and methods for radio tracking freshwater fish. Agricultural Experimental Station Misc. Rep. 152-1978., University of Minnesota, Minneapolis, Minnesota.

Wolfert, D.R. 1963. The movements of walleyes tagged as yearlings in Lake Erie. Trans. Amer. Fish. Soc. 92:414-420.